Adaptive Hydraulics (AdH) Version 4.7 Sediment Transport User Manual

A TWO-DIMENSIONAL MODELING SYSTEM DEVELOPED BY THE COASTAL AND HYDRAULICS LABORATORY

December 2021

US Army Corps
of Engineers®
Engineer Research and
Development Center

Abstract: Guidelines are presented for using the US Army Corps of Engineers (USACE) AdH modeling software to model two-dimensional shallow water problems with sediment transport (i.e. AdH linked to SEDLIB). This manual describes the inputs necessary to utilize the SEDLIB sediment transport library from within AdH, to perform coupled hydrodynamic, sediment, and morphological computations.

The SEDLIB sediment transport library is intended to be of general use and, as such, examples are given for basic sediment transport of cohesive, noncohesive, and mixed suspended sediment loads and bed load.

DISCLAIMER: The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products. All product names and trademarks cited are the property of their respective owners. The findings of this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

DESTROY THIS REPORT WHEN NO LONGER NEEDED. DO NOT RETURN IT TO THE ORIGINATOR.

Table of Contents

1 Introduction

The Adaptive Hydraulics (AdH) code is a finite element, numerical modeling package that can be used to model a wide-range of flow conditions. This includes both saturated and unsaturated 3D groundwater flow, 2D overland flow, 3D Navier-Stokes flow, 3D shallow water flow, and 2D (depth averaged) shallow water flow. However, the information contained in this manual is intended for application to the 2D shallow water flow module only.

AdH can be used in a serial or multiprocessor mode and on various operating systems after appropriate compilation. A single executable is available for multiprocessor and serial on a given operating system but different executables are needed for running on different operating systems.

The adaptive feature of AdH consists of its ability to dynamically refine and relax the spatial resolution (model mesh) and temporal resolution (time step) such that both model stability, accuracy and performance are optimized.

The ability of AdH to allow the domain to wet and dry as flow conditions or water surface elevations change is suitable for shallow marsh environments, beach slopes, floodplains and the like.

AdH can simulate subcritical, transcritical and supercritical flow conditions within the same domain. Boundary conditions can also be specified for both supercritical and subcritical conditions.

AdH has the ability to simulate several special conditions that are pertinent to many common shallow water problems, including vessel movement, ice cover, the influence of training structures and bridge decks, the influence of culvert entrances, and the presence of flow control structures such as weirs, flap and sluice gates, etc.

AdH can simulate the transport of conservative tracers, salinity, water temperature, and sediment transport that is coupled to bed and hydrodynamic changes.

AdH is developed and maintained at the Coastal and Hydraulics Laboratory (CHL) and has been used to model such varied conditions as sediment transport in sections of the Mississippi River (Heath et al., 2015; Sharp et al., 2013), tidal conditions in southern California (Tate et al., 2009), vessel traffic in the Houston Ship Channel (Tate and Ross, 2009), dam breaks (Savant et al., 2011), large scale terrestrial flooding (Tate et al. 2012) along with numerous other applications.

In General, AdH-2D can be applied to problems such as the following:

1) Subcritical riverine or channel flows
2) Supercritical riverine or channel flows
3) Tidal flows
4) Dam and levee break flows
5) Flooding due to overland flow conditions: urban and others
6) Baroclinic transport (salinity, heat, as well as sediment induced)
7) Sediment transport

The code is designed to work in conjunction with the DoD Modeling Systems (XMS), developed and distributed by Aquaveo, Inc. The Surface Water Modeling System (SMS) is a modeling package for building models, running simulations, and visualizing results. However, the model setup and results can be performed through many different tools as long as the file formats are correct.

Additional information on AdH can be obtained at the AdH website, https://www.erdc.usace.army.mil/Locations/CHL/AdH/. The basic 2D shallow water equations and their formulation in AdH are provided in Savant et al. 2020.

1.1 Sediment Transport

AdH allows the user to calculate the transport of cohesionless sediment, cohesive sediment, and mixed sediments. The model is capable of running multiple grain sizes in a single simulation. These computations are performed through a link with SEDLIB.

SEDLIB is a sediment transport library. It is capable of solving problems consisting of multiple grain classes, cohesive and cohesionless sediment types, and multiple layers. It calculates erosion and deposition processes simultaneously, and

Sign Convention

The sign convention in AdH is the standard Cartesian coordinate system and flow into the control volume is positive.

A note on units

AdH is designed so that the user can specify the unit system to use. However, all parameters must be consistent in that they are all given in English units or SI units and not mixed.

The geometry file, boundary condition file, and hotstart file must all be given in the same unit system. There is no card that directly specifies the units being used. Rather, AdH uses the values given and calculates with them. If any equations internal to AdH are unit specific, the density or gravity terms are used to decipher which system is being used.

This manual will give unit specifications where necessary in dimensional form.

The exception to allowing the user to determine the unit system is when sediment transport is being simulated. The sediment transport equations employed in SEDLIB are valid for SI units only. This means that all of the input files must also be given in SI units. **Sediment transport must be in SI units.**

simulates such bed processes as armoring, consolidation, and discrete depositional strata evolution.

The SEDLIB library system is designed to link to any appropriate hydrodynamic code (e.g., AdH). The hydrodynamic code must be capable of performing advection diffusion calculations for a constituent. SEDLIB interacts with the parent code by providing sources and sinks to the advection diffusion solver in the parent code. The solver is then used to calculate suspended load transport (for silt and clay classes), both bedload and suspended load transport (for sand classes) and bedload transport (for gravel classes), for each grain class. The sources and sinks are passed to the parent code via a source/sink bed sediment flux, for both suspended load and bedload.

The sediment is transported separately as suspended load and bed load. Each grain class is transported as a moving constituent. So, in making a sediment transport calculation, one must determine how many grain classes are going to be modeled. Sediment calculations also depend on the number of layers used to define the bed strata, as well as how the sediment is distributed within the bed. Sediment modeling requires much more site specific data for the model set up than does hydrodynamic modeling alone. Also, small changes in these parameters can lead to large changes in the solutions, since morphologic change is the time-integrated result of everything that has happened before.

The AdH and SEDLIB developers recommend that anyone using AdH and SEDLIB to model sediment transport be familiar with the basic principles of both sediment transport and of numerical modeling. Large amounts of observed data and analysis are often needed when attempting to develop and validate a sediment transport model of a field site with any numerical model, and AdH is no exception. Please take your time when setting up your model and make all necessary sensitivity simulations to ensure that you fully understand the dynamics of the system and the driving forces. Without such careful analysis, it is easy to draw false conclusions from the model results, and hence provide misleading information to your sponsors. A good rule of thumb is this: if you cannot explain it, you don't understand it.

1.2 Files Needed to Run AdH

The same three input files necessary to run AdH are also needed when sediment is included. No additional files are required. The three files are the mesh file, the boundary condition file and the hotstart file.

The **mesh file** must be constructed first and can be generated directly with GMS (2D or 3D) or SMS (2D).

Once a mesh file has been constructed, the **boundary conditions** for the problem and operating parameters for AdH must be specified in the boundary condition file.

The **hotstart** file is then generated to establish the initial conditions of the problem.

Once the three required files have been created, pre_AdH is run and it creates the necessary input file for AdH. Then the AdH model is run. The commands are:

pre_adh filename
adh filename

where *filename* is the root of the model's filenames, i.e. for a model named pl8_AdH the following three files would be required pl8_AdH.3dm, pl8_AdH.hot and pl8_AdH.bc. All three files must have the same *filename* as their root followed by one of three suffixes. After the model is run, GMS or SMS can be used to visualize the results.

1.3 Specifically for Sediment Modeling

When running AdH with sediment transport, there are a few required changes to some of the mandatory cards. Additional sediment specific cards are also required in order to model suspended and bed load sediment.

The mesh file can remain unchanged unless material designations need to be modified to match bed layer definitions. The hotstart file can also remain unchanged unless the initial conditions need to include concentrations or other sediment specific initial conditions, or unless one is hotstarting a sediment transport simulation, in which case all of the relevant sediment parameters must be included in the hotstart file. These will be discussed in the hotstarting section.

Most of the modifications for sediment transport modeling will occur in the boundary condition files. This manual will describe the changes that must occur to a previously generated set of input files (such as for a hydrodynamic simulation) along with all of the options for modeling sediment in AdH using SEDLIB.

1.4 A Note on Units and Sediment Transport in AdH

Although one can use any consistent units convention to run AdH, for sediment transport computations, it is required to simulate AdH in metric units. Specifically, all length quantities are given in meters, and all mass quantities are given in kilograms. This is done to avoid complex conversions between the inconsistent units that are associated with many of the typical sediment transport related quantities. These conversions can result in inadvertent errors and unnecessary confusion. To avoid these difficulties, AdH with SEDLIB is run in metric units, and the user can convert outputs to whatever convention they desire.

The one partial exception to the metric convention for AdH/SEDLIB is the units of concentration. For AdH/SEDLIB, concentration is given in units of micromass per unit mass, or parts per million by mass (ppm). Parts per million by mass is herein defined as mass of sediment divided by mass of solute, times 1,000,000.

In metric units, 1 cubic centimeter of water happens to weigh 1 gram. Because of this, for relatively low sediment concentrations (such as those we typically model), ppm is essentially equal to mg/l. Hence, although the concentrations given for AdH may be expressed in terms of mg/l, which has units of mass per volume, the actual dimensions of concentration used in AdH are dimensionless (mass per unit mass, times 1,000,000).

1.5 Control Card Categories

The sediment control cards listed here are in addition to those required to run hydrodynamics only. These cards include some that are necessary to run any constituent (each sediment grain class is a separate constituent) and some that are necessary to run sediment. There are also several cards that are optional. In order to help clarify which cards are necessary and which are optional for sediment transport calculations, required cards are annotated with comments in red capitalized italic text, and optional cards are annotated with comments in green capitalized italic text. The sediment control cards and their categories are:

Operation Parameters	
OP TRN	Transport Quantities *REQUIRED*
Constituent Properties	
CN CLA	Fine Sediment (Clay, Silt) *REQUIRED FOR SILT AND CLAY TRANSPORT*
CN SND	Coarse Sediment (Sand, Gravel, Cobble) *REQUIRED FOR SAND GRAVEL, AND COBBLE TRANSPORT*
Material Properties	
MP TRT	Transport Refinement Tolerance (Transport Constituent Property) *REQUIRED*
MP NBL	Number of Bed Layers *REQUIRED*

MP SBA	Bed layer distribution applied to all nodes *REQUIRED (ALTHOUGH CAN BE APPLIED BY NODE OR MATERIAL TYPE INSTEAD)*
MP SBN	Bed layer distribution applied to selected nodes *REQUIRED (SEE ABOVE)*
MP SBM	Bed layer distribution applied by material *REQUIRED (SEE ABOVE)*
MP CBA	Cohesive bed sediment applied to all nodes *OPTIONAL (ALTHOUGH CAN BE APPLIED BY NODE OR MATERIAL TYPE INSTEAD)*
MP CBN	Cohesive bed sediment properties applied to selected nodes *OPTIONAL (SEE ABOVE)*
MP CBM	Cohesive bed sediment properties applied by material *OPTIONAL (SEE ABOVE)*
MP NCP	Number of consolidation time intervals *OPTIONAL*
MP CPA	Consolidation properties applied to all nodes *OPTIONAL (ALTHOUGH CAN BE APPLIED BY NODE OR MATERIAL TYPE INSTEAD)*
MP CPN	Consolidation properties applied to selected nodes *OPTIONAL (SEE ABOVE)*
MP CPM	Consolidation properties applied by material *OPTIONAL (SEE ABOVE)*
	Toggle off bed displacement for all nodes *OPTIONAL (ALTHOUGH CAN BE APPLIED BY MATERIAL TYPE INSTEAD)*
MP NDM	Toggle off bed displacement by material type *OPTIONAL (SEE ABOVE)*
MP LSM	Local scour imposition by material type *OPTIONAL*
MP BLD	Bedload diffusion scale factor *OPTIONAL*
MP DRD	Dredge by material type *OPTIONAL*
MP DRP	Dredge Placement by material type *OPTIONAL*

Sediment Process Controls

SP NSE	Noncohesive Suspended Sediment Entrainment *OPTIONAL: DEFAULT WILL BE USED IF NOT INVOKED*
SP NBE	Noncohesive Bedload Sediment Entrainment *OPTIONAL: DEFAULT WILL BE USED IF NOT INVOKED*
SP HID	Noncohesive Hiding Factor *OPTIONAL: DEFAULT WILL BE USED IF NOT INVOKED*
SP CSV	Concentration Dependent Cohesive Settling Velocity *OPTIONAL*
SP WWS	Bed Shear Stress due to Wind waves *OPTIONAL*
SP_SIF	Bed sediment infiltration of fines *OPTIONAL*

Solution Controls	
DB TRN	Dirichlet – Transport *OPTIONAL*
NB TRN	Natural – Transport *OPTIONAL*
EQ TRN	Equilibrium Coarse Sediment Transport Boundary *OPTIONAL*

Vegetation Model Controls	
VEG	Vegetation model basic parameters *OPTIONAL*
MP VGM	Vegetation Model properties by material type *OPTIONAL*

2 Operation Parameters

The number of transported quantities is given on an OP TRN card. The OP TRN card is a required input card. If the problem does not involve transport (sediment or constituent), zero (0) quantities are specified on the OP TRN card. If 2 sediment classes and salinity are being modeled then three (3) will be specified on the OP TRN card.

In addition, if transport equations are not being modeled, no transport properties or boundary conditions should be specified. An error message will be displayed if transport properties are included in the input file but no transport quantities have been specified.

The following card specifies one transported quantity:

OP TRN 1

Operation parameter cards

OP TRN

TRANSPORT EQUATIONS

Field	Type	Value	Description
1	char	OP	Card type
2	char	TRN	Parameter
3	int	≥ 0	Total number of transported materials (includes all transport types: vorticity, temperature, salinity, sand, clay, etc.)

3 Generic Transport Properties

Material properties are used to define features and parameters associated with a collection of elements in the model domain, as defined in the mesh file. Material property cards begin with **MP** and are followed by specific card indicators. Some **MP** cards are used for hydrodynamics and others are specific to sediment transport.

3.1 Mesh refinement

Mesh refinement is defined on the **MP ML** card for both hydrodynamic and sediment models. An **MP TRT** card is required to define the tolerance for the sediment adaption. A transport refinement tolerance is required for all transport (sediment and constituent) classes for all materials. Just as with hydrodynamics, if the transport solution error on an element exceeds the transport refinement error tolerance given on the **TRT** card, the element is split. This card is only a tolerance, however. The material must be set to allow refinement in order for any adaption to occur.

In AdH, the error is defined in terms of the root mean square of the mass conservation residual at each node in the element. This technique indicates which elements require more resolution in order to properly resolve local gradients. More details on the error indicator can be found in Tate et al (2006).

The error indicator for (sediment) concentration is expressed mathematically as follows:

$$K_j = \sum_{i=1}^{i=n_j} \left(h_i \frac{\partial c_i}{\partial t} + u_i h_i \frac{\partial c_i}{\partial x} + c_i h_i \frac{\partial u_i}{\partial x} + v_i h_i \frac{\partial c_i}{\partial y} + c_i h_i \frac{\partial v_i}{\partial y} \right)^2 \qquad (1)$$

$$E_j = A_j \sqrt{K_j} \qquad (2)$$

Where j is the element number, i is a counter for the nodes in element j, n_j is the total number of nodes in element j, A_j is the surface area of element j, c is the constituent (sediment) concentration, h is the water depth, u is the x-velocity, v is the y-velocity, and E_j is the transport solution error associated with element j.

In models with transport, the larger of the hydro error or the transport error will determine each element's value in the *project_name_*err.dat file It is this value that is used to determine whether or not an element is refined or relaxed. The value given in the *project_name_*err.dat file is normalized by the refinement tolerance. This means that values greater than 1 can be interpreted as locations where the error exceeds the refinement tolerance.

Some users prefer to examine the error results for each transported quantity separately. To facilitate this, the hydrodynamic and transport errors are stored separately in files labeled as such: *project_name_*err_hydro.dat and *project_name_*err_con#.dat. The values stored in these files are not normalized by the refinement tolerance: they are the actual computed values of error.

The unrefine tolerance is currently set within the code as 10 percent of the refine tolerance for both flow conditions and transport conditions. When the grid solution error improves, the elements are recombined, although never coarser than the original mesh.

During normal model operations, the solutions are always saved to the original (coarse) mesh. This means that the user will not see the adapted mesh, even though the solutions that are shown are computed on the adapted mesh. If the user desires to see the adapted mesh, he/she can invoke the **PC ADP** card (see below).

The following is an example of how to set the adaption parameters. For this case, for material type 1, a maximum of 5 levels of adaption are permitted (i.e. the individual elements can be split 5 times). For material type 1, the refinement tolerance for constituent 1 is 100, and the refinement tolerance for constituent 2 is 50.

MP ML 1 5
MP TRT 1 1 100
MP TRT 1 2 50

Different material types can have different levels of refinement. Some experimentation with the error tolerance is usually necessary to gain the desired level of refinement. If desired, the adapted meshes can be output during the simulation by including a **PC ADP** card. By including this card, the mesh and associated solution files will be saved at the time step intervals specified on the output control card. The output files will be named like so: “filename.3dm-timestep#.0”, “filename.dep-timestep#.0”, “filename.ovl-timestep#.0” which is a geometry file for each time step, the depths for each time step, and the velocities for each time step.

3.2 Turbulent Diffusion and Dispersion

Diffusion and dispersion are handled with the eddy viscosity cards and must be defined for every material with either an **MP EEV** or **MP EVS** card (see the AdH Hydrodynamic User Manual). Turbulent diffusion of transport constituents is defined on the **MP DF** card. This diffusion rate must be specified for each material and constituent. This diffusion card is only required when using the **EVS** option. When using the **EEV** option the diffusion is computed based on the parameters provided on the **EEV** card. (Note that vorticity induced dispersion is always active when vorticity transport is active). Also, an optional **MP BLD** card can be invoked to scale the bedload diffusion, if desired.

Material property cards

MP ML

REFINEMENT LEVELS

Field	Type	Value	Description
1	char	MP	Card type
2	char	ML	Parameter
3	int	≥ 1	Material type ID number
4	int	≥ 0	Maximum number of refinement levels

MP TRT

TRANSPORT CONSTITUENT REFINEMENT TOLERANCE

Field	Type	Value	Description
1	char	MP	Card type.
2	char	TRT	Parameter.
3	int	≥ 1	Material type ID number
4	int	≥ 1	Constituent ID number
5	real	≥ 0	Error tolerance for refinement terms

MP DF

TURBULENT DIFFUSION RATE

Field	Type	Value	Description
1	char	MP	Card type
2	char	DF	Parameter
3	int	≥ 1	Material type ID number
4	int	> 0	Constituent ID number
5	real	≥ 0.0	Turbulent diffusion rate

MP BLD

BEDLOAD DIFFUSION

Field	Type	Value	Description
1	char	MP	Card type

2	char	BLD	Parameter
3	int	≥ 0	Material type ID number
4	int	≥ 0	Bedload diffusion constant K_{BL} (default = 1.0)

The bedload diffusion is computed as follows:

$$D_{BL} = 2.5 K_{BL} h u_*$$

Where D_{BL} is the bedload diffusion, is the bedload diffusion constant (default = 1.0), h is the water depth, and u_* is the shear velocity.

4 Sediment Transport Specific Properties

In addition to the general transport properties that are provided above, many properties are required for the sediment definitions within the AdH input files. These properties include details to define the grain properties (such as grain size and porosity) the bed layering (such as layer thickness and grain distributions) and the sediment processes (such as the entrainment function).

4.1 Definitions and Properties of Coarse Sediment (Sand, Gravel and Cobble) and Fine Sediment (Silt and Clay)

In SEDLIB, coarse sediments (sands, gravels and cobbles) are defined as sediment classes with a grain diameter greater than 63 µm. Fine sediments (silts and clays) are defined as sediment classes with a grain diameter less than 63 µm.

Sediment beds consisting of only coarse sediment classes are essentially cohesionless. That is, the sediment grains are of a large enough size that the electrostatic forces between the particles are very small relative to gravitational, inertial, and viscous forces, and are therefore negligible. This means that coarse grains tend to both deposit and to erode grain-by- grain; hence the erosional and depositional properties of coarse sediment can be defined purely as grain properties. The transport of coarse sediments can occur as either bedload transport (particles hopping, rolling, or sliding along the bed, typically forming moving bedforms), or suspended bed material load transport (particles injected into the flowfield, subjected to turbulent fluxuations, and translating multiple dune-lengths downstream before making contact with the bed again), or both. For simplicity, however, SEDLIB transports grains with a diameter greater than 2500 µm as bedload only (the transport equations that are typically used to describe the transport of sediments coarser than this are bedload or total load equations, so for simplicity their movement is lumped into one mode of transport).

Fine sediment beds consist of silt and clay classes. The smallest of the fine sediment classes, consisting of grains with a grain diameter of 3.9 µm or finer, are clays. Clays are considered fully cohesive classes. Cohesive sediment is sediment that is of such a small size that the electrostatic forces between particles become significant (relative to gravitational, inertial, and viscous forces).

Grains with a diameter greater than 3.9 microns but smaller than 63 microns are considered silts. Silts are also cohesive, but in AdH/SEDLIB, their cohesiveness is assumed to reduce in proportion to their size (i.e. coarser silts are less cohesive than finer silts).

Cohesive sediment behaves differently than cohesionless sediment. Cohesiveness can cause flocculation of settling sediments, thus altering the depositional behavior. Cohesiveness also results in erosion behavior that is more generally a property of the condition of the sediment bed than a property of the individual grains. In SEDLIB, the transport of fine sediments is modeled as suspended load only (i.e. sediment suspended into the water column, that does not make contact with the bed again unless the shear stress drops below some user-defined critical value).

In rivers, fine sediment transport is often referred to colloquially as “wash-load”, meaning that the fines are not typically found in the bed material samples. However, even in rivers, fine sediments can settle in quiescent backwaters. In estuaries and reservoirs, the behavior of fine sediments is typically much more complex, and the “wash-load” paradigm is much less relevant.

When coarse and fine sediment classes are mixed together in the sediment bed, the behavior becomes even more complex. A bed consisting of both cohesive and cohesionless sediment classes may exhibit cohesive or cohesionless behavior, depending on the fraction of silt and clay classes that are present in the mixture. The behavior of mixed cohesive and cohesionless sediment beds is discussed in more detail in section 4.5.

4.2 General Sediment Boundary Condition Input

The following card descriptions are for general parameters that are applicable for any sediment simulation. Subsequent sections will describe parameters needed for specific sediment types.

The number of bed layers is given with the **NB NBL** card. This card requires the number of layers and a protocol flag. The bed layer thickness assignment protocol is 0 for bed layer thickness assigned directly on sediment bed fraction (**SB**) cards, or 1 for bed layer thickness assigned by strata elevation horizon on **SB** cards.

The **SB** card defines the grain class fraction of each sediment class within the individual bed layers (i.e. the grain class distribution). After the layer number (where layer 1 is the deepest layer, and the maximum layer number is the layer at the bed surface), the thickness and grain class distribution for that layer are listed. This distribution can be given by individual node (**SBN**), by material type (**SBM**), or for all nodes at once (**SBA**). Note that the model overwrites any prior designation with subsequent information for the same location, so for convenience one could specify an **SBA** card first, followed by a few material types, followed by individual nodes.

An example is given below. For two layers and 3 grain classes we might have the following:

MP NBL 2 0
MP SBA 1 0.5 0.0 0.4 0.6
MP SBA 2 0.5 0.4 0.3 0.3

The **MP NBL** card tells AdH to expect two bed layers to be defined on the sediment bed fraction cards and that thickness magnitude will be specified directly (bed layer thickness assignment protocol =0). **MP SBA** means that the sediment bed description for all nodes will be used. The next number is the layer number, followed by the layer thickness. The final three numbers are the fractions of each of the sediments shown in the **CN SND** cards. In this example, there are three sediment grains and two layers. Layer 1 is the deepest (or bottom) layer, and layer 2 is the top layer.

Note that the sediment grain distribution must sum to exactly 1 for each assigned bed layer.

If desired, individual materials and/or nodes can now be designated with **SBM** or **SBN** cards, and these nodes would be modified to reflect the difference.

Note that it is often desirable to have several layers of zero thickness specified at the bed surface (i.e. the highest layer numbers). These are used by the model as depositional layers, each one storing information from discrete depositional events, and thereby generating new strata in the bed.

When using the strata elevation option (bed layer thickness assignment protocol =1), the bed layer thickness is computed based on the elevation of each node. If the bed elevation is above the bottom elevation of a given layer (as assigned on the **SB** card), then that layer thickness is zero. If the bed elevation is below the bottom elevation of a given layer and above the bottom elevation of the layer below, then the bed thickness is the difference between these two elevations.

The elevation horizon option functions as follows:

For layer n, the thickness of the layer is equal to:

$$t_n = MAX\left[\left(MIN\left(\eta_{n+1}, \eta_{bed}\right) - \eta_n\right), 0\right] \tag{3}$$

Where η is elevation.

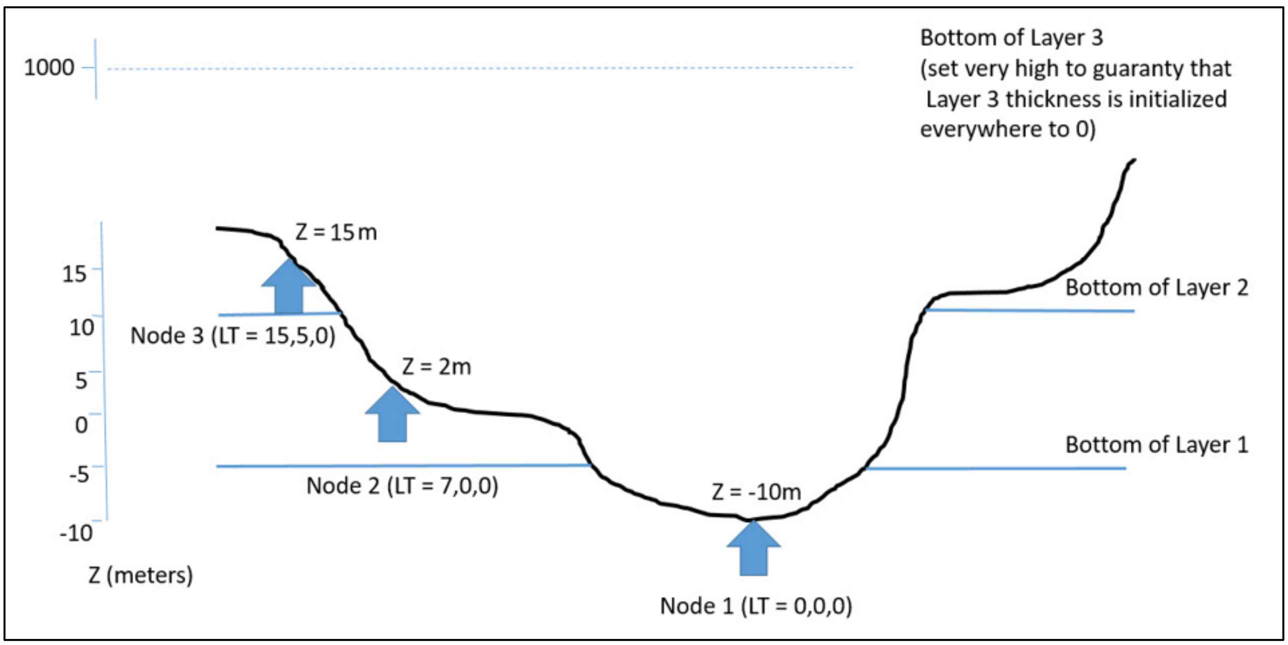
For example, the following layers are defined (with one grain for simplicity):

MP NBL 3 1

SBA -5 1.0
SBA 10 1.0
SBA 1000 1.0

The code will then look at the z coordinate for each node and assign layer thicknesses. If node 1 has a z coordinate of -10 this elevation is below the deepest defined elevation on the cards so all three layers will have zero thicknesses. For node 2 with a z coordinate of 2, the layer thicknesses are 7, 0, and 0. For node 3 with a z coordinate of 15, the layer thicknesses are 15 5, and 0. See Figure 1 for an illustration of the specification of nodes 1-3, where "LT" stands for "layer thickness."

Figure 1. Illustration of layer thickness specification by elevation horizon



Note that, when using this layer thickness protocol, the best way to define zero thickness layers is to assign a large number (such as 1000) to the elevation horizon of the layer, such that the number chosen is large enough that no elevation in the domain exceeds it.

Sediment boundary conditions can be specified with **NB TRN** and **DB TRN** cards. These cards function much like the hydrodynamic and transport cards. The natural boundary condition will apply a suspended sediment mass flux along a defined edge and the dirichlet boundary condition will apply a suspended sediment concentration at a list of nodes. These boundary conditions must be defined for each grain class. Note that these boundary conditions define suspended load only: bedload flux at the boundary is simply lumped into this applied suspended load, and then the model determines what mode the sediment should transport in as the transport computations proceed into the model domain.

MP NBL

NUMBER OF SEDIMENT BED LAYERS

Field	Type	Value	Description
1	char	MP	Card type
2	char	NBL	Parameter
3	int	≥ 0	Number of bed layers for sediment transport (layer number begins with the bottom-most layer)
4	int	0 or 1	Bed layer thickness assignment protocol 0 = bed layer thickness assigned directly on SB cards 1 = bed layer thickness assigned by strata elevation horizon on SB cards

The elevation horizon option functions as follows:

For layer n, the thickness of the layer is equal to: $t_n = MAX\left[\left(MIN\left(\eta_{n+1}, \eta_{bed}\right) - \eta_n\right), 0\right]$

Where η is elevation

MP SBN

SEDIMENT BED INITIALIZATION APPLIED TO SELECTED NODES

Field	Type	Value	Description
1	char	MP	Card type
2	char	SBN	Parameter
3	int	> 0	Bed layer ID number
4	int	> 0	The node number from which to start
5	int	> 0	The node number at which to end
6	real	≥ 0.0	The bed layer thickness or strata elevation horizon
7	real	≥ 0.0	The grain class fraction for the first sediment
8	real	≥ 0.0	The grain class fraction for the second sediment
#	real	≥ 0.0	The grain class fraction for the final sediment

MP SBA

SEDIMENT BED INITIALIZATION APPLIED TO ALL NODES

Field	Type	Value	Description
1	char	MP	Card type
2	char	SBA	Parameter

3	int	> 0	Bed layer ID number
4	real	≥ 0.0	The bed layer thickness or strata elevation horizon
5	real	≥ 0.0	The grain class fraction for the first sediment
6	real	≥ 0.0	The grain class fraction for the second sediment
#	real	≥ 0.0	The grain class fraction for the final sediment.

MP SBM

SEDIMENT BED INITIALIZATION APPLIED BY MATERIAL

Field	Type	Value	Description
1	char	MP	Card type
2	char	SBM	Parameter
3	int	> 0	Bed layer ID number
4	int	> 0	Material type ID number
5	real	≥ 0.0	The bed layer thickness or strata elevation horizon
6	real	≥ 0.0	The grain class fraction for the first sediment
7	real	≥ 0.0	The grain class fraction for the second sediment
#	real	≥ 0.0	The grain class fraction for the final sediment

NB TRN

NATURAL BOUNDARY CONDITION - TRANSPORT

Field	Type	Value	Description
1	char	NB	Card type
2	char	TRN	Parameter
3	int	≥ 1	String ID number (edge)
4	int	≥ 1	Constituent ID number
5	int	≥ 1	Series ID number that contains the constituent concentration (units are ppm by mass)

DB TRN

DIRICHLET - TRANSPORT

Field	Type	Value	Description
1	char	DB	Card type
2	char	TRN	Parameter
3	int	≥ 1	String ID number (node)
4	int	≥ 1	Constituent ID number
5	int	≥ 1	Series ID number that contains the constituent concentration (units are ppm by mass)

4.3 Boundary Condition Input for Coarse Sediment Only (Sand, Gravel and Cobble)

The required characteristics to define a coarse sediment grain class are its grain diameter, its specific gravity, and its porosity. These are supplied via the **CN SND** cards. **SND** stands for sand. Here is an example:

CN SND 1 1.0 1.E-4 2.65 0.3
CN SND 2 1.0 5.E-4 2.65 0.3
CN SND 3 1.0 1.E-3 2.65 0.3

Beginning after the **CN SND** are the constituent number, the reference concentration for this grain class, grain diameter, the specific gravity, and the porosity. Note that the reference concentration, like all sediment concentrations given in AdH, is in units of micro-mass per unit mass, or parts per million by mass (ppm). The reference concentration is commonly specified as 1 ppm, but one can also use any typical value of the suspended sediment concentration that is characteristic for the site being modeled.

An added (and very useful) boundary condition option is available for cohesionless sediment transport (sand and gravel). This is the equilibrium transport boundary condition (**EQ TRN** card). When this condition is specified, the concentration that AdH computes and applies at the boundary is the concentration that is required for a state of equilibrium to exist at the boundary. This boundary condition is applied for both suspended bed material load and bedload (i.e. both suspended bed material load and bedload equilibrium conditions are specified). Since this boundary condition varies both in space and time, and is dependent on the local shear stress at each node, it can only be applied as a nodal boundary condition (i.e. it cannot be applied at a natural boundary condition using an edge string: it must be applied as a Dirichlet boundary condition using a node string). For such an equilibrium condition, almost no sediment will erode or deposit at the specified boundary. This condition is specified with an **EQ TRN** card followed by the node string number where it is to be applied, and the constituent number for the grain being applied.

CN SND

COHESIONLESS SEDIMENT (SAND)

Field	Type	Value	Description
1	char	CN	Card type
2	char	SND	Parameter
3	int	≥ 1	The constituent ID number
4	real	> 0	Characteristic concentration
5	real	> 0	Grain diameter
6	real	> 1	Specific gravity
7	real	> 0	porosity for newly deposited sediment

EQ TRN

EQUILIBRIUM SAND TRANSPORT BOUNDARY CONDITION

Field	Type	Value	Description
1	char	EQ	Card type
2	char	TRN	Parameter
3	int	≥ 1	String ID number (node)
4	int	≥ 1	Constituent ID number
5	int	≥ 0	placeholder

4.4 Boundary Condition Input for Fine Sediment Only (Silts and Clays)

The cohesive properties of silts and clays result in erosion behavior that is more generally a property of the condition of the sediment bed than a property of the individual grains. Therefore, the user must specify the erosion characteristics of the cohesive bed. In AdH, these erosion characteristics are governed by the following equation (Alishahi and Krone, 1964):

$$F_E = M\left(\frac{\tau}{\tau_c} - 1\right)^n \tag{4}$$

Where F_E is the erosion flux, M is the erosion rate constant, n is the erosion rate exponent, and τ_c is the critical shear stress for erosion.

Because of this cohesive behavior, it is necessary to define the erosional characteristics of the existing sediment bed independently of the general characteristics of the individual fine grains. The erosional characteristics of the existing sediment bed are (in general) highly site specific, and ample data must be collected to define coefficients that are appropriate for a given site.

The characteristics of the individual grains, however, are (in general) less site specific than the characteristics of the existing sediment bed, although the grain characteristics are still best determined by local observations. The depositional characteristics must be specified for each grain. AdH also requires erosional characteristics for each grain. These are needed in order to define the properties of any newly deposited sediment layer: that is, the erosional characteristics of a sediment layer that is deposited only after the model simulation has commenced.

Both the depositional characteristics and the erosional characteristics of *newly deposited* cohesive sediment are given on the **CN CLA** card (**CLA** stands for clay, although both clay and silt are specified with this card). The erosional characteristics of the existing sediment bed are given on the cohesive bed (**CB**) cards.

The parameters given on the **CN CLA** card are:

- Grain diameter
- Specific gravity
- Bed porosity (new deposit)
- Critical shear stress for erosion (new deposit)(τ_c)
- Erosion rate constant(new deposit) (M)
- Critical shear stress for deposition
- Grain settling velocity

Note that the erosion rate exponent (n) is assumed to be equal to 1 for newly deposited sediment (this is consistent with the observation of Parthenaides).

The following are examples of **CLA** cards for 2 fine sediment grains.

CN CLA 1 1.0 0.000001 2.65 0.88 0.014 0.00016 0.01 0.00006
CN CLA 2 1.0 0.00001 2.65 0.75 0.02 0.00018 0.015 0.00016

The reference concentration, like all sediment concentrations given in AdH is in units of micromass per unit mass, or ppm by mass.

In addition to these grain definitions, cohesive sediment beds require a **MP CB** card for each bed layer to define the cohesive properties of the layers.

The inputs to the **MP CB** cards include the following:

- Layer number
- Bed porosity
- Critical shear stress for erosion (τ_c)
- Erosion rate constant (M)
- Erosion rate exponent (n).

Here's an example of **MP CBA** cards for 2 bed layers:

MP CBA 1 0.5 0.1 0.00018 3.0
MP CBA 2 0.6 0.08 0.00016 2.0

As with the **SBA** card, the cohesive bed properties can be defined by all nodes (**CBA**), specific materials (**CBM**), or specific nodes (**CBN**). As with the previous bed definitions, the layer numbering begins with the bottom-most layer.

Note that **EQ TRN** cards cannot be used for cohesive sediments. The concept of an equilibrium concentration has no physical meaning for cohesive sediments, since (in general) simultaneous erosion and deposition does not occur. The natural and dirichlet transport boundary condition options (**NB TRN** and **DB TRN**) are used when defining suspended sediment inflow for cohesive material.

CN CLA

COHESIVE SEDIMENT (CLAY AND/OR SILT)

Field	Type	Value	Description
1	char	CN	Card type
2	char	CLA	Parameter
3	int	≥ 1	The constituent ID number
4	real	> 0	Characteristic concentration
5	real	> 0	Grain diameter
6	real	> 1	Specific gravity
7	real	> 0	porosity for newly deposited sediment
8	real	> 0	Critical shear stress for erosion for newly deposited sediment
9	real	> 0	Erosion rate constant for newly deposited sediment
10	real	> 0	Critical shear for deposition
11	real	> 0	Free Settling velocity

MP CBN

COHESIVE BED SEDIMENT PROPERTIES APPLIED TO SELECTED NODES

Field	Type	Value	Description
1	char	MP	Card type
2	char	CBN	Parameter
3	int	> 0	Bed layer ID number
4	int	> 0	The node number from which to start
5	int	> 0	The node number at which to end
6	real	≥ 0.0	The porosity for the bed layer
7	real	≥ 0.0	The critical shear stress for erosion for the bed layer
8	real	≥ 0.0	The erosion rate constant for the bed layer
9	real	≥ 0.0	The erosion rate exponent for the bed layer

MP CBM

COHESIVE BED SEDIMENT PROPERTIES APPLIED BY MATERIAL

Field	Type	Value	Description
1	char	MP	Card type
2	char	CBM	Parameter
3	int	> 0	Bed layer ID number

4	int	> 0	Material type ID number
5	real	≥ 0.0	The porosity for the bed layer
6	real	≥ 0.0	The critical shear stress for erosion for the bed layer
7	real	≥ 0.0	The erosion rate constant for the bed layer
8	real	≥ 0.0	The erosion rate exponent for the bed layer

MP CBA

COHESIVE BED SEDIMENT PROPERTIES APPLIED TO ALL NODES

1	char	MP	Card type
2	char	CBA	Parameter
3	int	> 0	Bed layer ID number
4	real	≥ 0.0	The porosity for the bed layer
5	real	≥ 0.0	The critical shear stress for erosion for the bed layer
6	real	≥ 0.0	The erosion rate constant for the bed layer
7	real	≥ 0.0	The erosion rate exponent for the bed layer

4.5 Converting between bed porosity, wet bulk density, and dry bulk density

The versions of AdH previous to AdHv4.7 required the user to specify porosity for cohesionless properties, and wet bulk density for cohesive properties. This was done in deference to the conventions typically used by scientists and engineers for these problems.

For AdHv4.7, this mixed convention has been abandoned. In AdHv4.7, all bed properties are assigned in terms of porosity. This has been done for 2 reasons.

1. Utilizing a single convention for all types of beds avoids confusion for users, and reduces the possibility of user-error when converting between conventions.

2. Of the 3 methods typically used to specify bed properties (porosity, dry bulk density, wet bulk density), only porosity is sufficiently general to permit modeling of sediments with different specific gravity constants. Both wet bulk density and dry bulk density cannot be specified independently of the specific gravity of the grains present in the bed.

Note: if a user has a previously generated sediment hotstart file from a previous version of Adh, where the bed properties were defined in terms of wet bulk density instead of porosity, the hotstart file can still be used in AdHv4.7. Adhv4.7 will recognize that the bed properties are given in wet bulk density on the hotstart file, and will convert them to porosity before using them to define the initial conditions in the model.

In order to facilitate the easy conversion between these various methods of specifying the bed conditions, Table 1 is given to provide equations that can be used to perform the conversions. Note that, in Table 1, p is porosity, s is specific gravity, and ρ is the density of fresh water (~1000 kg/m3). Note also that the conversions in this table are only appropriate for sediment beds with a constant specific gravity among all grain classes. Beds consisting of grains with variable specific gravity must be first converted to a constant specific gravity value equal to the mass weighted average of the values of each grain.

Table 1: Equations to Convert Between Porosity, Dry Bulk Density, and Wet Bulk Density

	Convert from porosity (p)	Convert from dry bulk density ($\rho_{BD.D}$)	Convert from wet bulk density ($\rho_{BD.W}$)
Convert to porosity (p)		$p=\left(1-\frac{\rho_{BD.D}}{\rho s}\right)$	$p=\left(\frac{s}{s-1}\right)\left(1-\frac{\rho_{BD.W}}{\rho s}\right)$
Convert to dry bulk density ($\rho_{BD.D}$)	$\rho_{BD.D}=\rho s(1-p)$		$\rho_{BD.D}=\rho_{BD.W}-\rho p$
Convert to wet bulk density ($\rho_{BD.W}$)	$\rho_{BD.W}=\rho s(1-p)+\rho p$	$\rho_{BD.W}=\rho_{BD.D}+\rho p$	

4.6 Model Protocols for Mixed Sediments (coarse and fine sediments)

When cohesive and cohesionless sediment classes are mixed together in the sediment bed, the behavior becomes even more complex than it is for purely cohesive or cohesionless sediment beds.

The cohesiveness of a mixed sediment bed varies in proportion to the silt and clay fraction of the mixture. A bed consisting of both cohesive and cohesionless sediment classes may exhibit cohesive or cohesionless behavior, depending on the fraction of silt and clay classes that are present in the mixture.

The cohesive fraction of the sediment bed is computed with the following algorithm:

$$\beta_{CF} = \sum_{i=1}^{ngc} \beta_i \phi : \phi = \frac{d_{NCL} - d_i}{d_{NCL} - d_{CL}} : 0 < \phi \lhd 1 \qquad (5)$$

Where:

β_{CF} = the cohesive fraction in the bed layer
β_i = the fraction of each grain in the bed layer
d_i = the diameter of each grain the bed layer
d_{CF} = the limiting diameter for cohesive grains (= 3.9E-6 m)
d_{NCF} = the limiting diameter for noncohesive grains (8.8E-6 m)

The fraction of cohesive material necessary for the bed layer to initiate cohesive erosional behavior ($\beta_{CF} = \beta_{CF.CI}$) has been set at 0.05 (i.e. 5%). The fraction of cohesive material necessary for the bed layer to achieve fully cohesive erosional behavior ($\beta_{CF} = \beta_{CF.CF}$) has been set at 0.1 (i.e. 10%). Sediment bed layers for which the value of β_{CF} falls between 5 and 10% exhibit erosional behavior that is linearly interpolated between fully cohesive and cohesionless behavior, according to the value of β_{CF} for the bed layer.

Fully cohesionless erosional behavior is defined by grain properties associated with each cohesionless grain, as determined by the entrainment algorithms selected by the user. Full cohesive erosional behavior is determined by the cohesive layer properties, as initially defined on the **MP CBA** or **MP CBM** cards.

Below is an example of 2 sands, 1 clay, and 1 silt being given in the same file The clay is distinguished from the silt by the assigned grain size, which is less than the maximum grain size for the clay fractions i.e. (3.9E-6):

```
CN SND  1  1.0  0.0001    2.65  0.3
CN SND  2  1.0  0.001     2.65  0.3
CN CLA  3  1.0  0.000001  2.65  0.88  0.01  0.00016326  0.01  0.00006
CN CLA  4  1.0  0.00001   2.65  0.75  0.01  0.00016326  0.01  0.00016
```

The sediment bed properties and the cohesive bed properties should also be defined in the boundary condition file, consistent with the way they are defined for fully cohesive beds.

4.7 Other Features

The features discussed in this section are additional to those required to model sediment transport in AdH with SEDLIB. These are optional features that users can take advantage of if they find them useful for a specific study.

4.7.1 SEDFLUME erosion rate input

SEDFLUME is a field- or laboratory-deployable flume for quantifying cohesive sediment erosion (McNeil et al. 1996). It is a device that can be used to make direct measurements of core erosion rates.

SEDFLUME erosion rate data are given as a table of values sorted by bed layer and shear stress. For a given bed layer, the erosion rate can be found by interpolating between the shear stress values to find the appropriate value for the applied bed shear stress.

If the user applies SEDFLUME data to a given material type, the erosive behavior for that material type will be governed by the parameters given on the SEDFLUME card. These parameters will override both the standard noncohesive grain erosion rates, and any cohesive erosion rates specified on **MP CBA, MP CBM** or **MP CBN** cards.

If the entire SEDFLUME layer is eroded, the erosional properties of the bed at this location revert to the default properties (i.e. standard noncohesive grain erosion rates, and any cohesive erosion rates specified on **MP CBA, MP CBM** or **MP CBN** cards.)

Note that the number of SEDFLUME shear stress intervals must be ≥ 2.

Also note that, for good modeling practice, it is adviseable to make sure the total number of bed layers is ≥ 2 plus the number of layers assigned SEDFLUME erosion rates. This is to ensure that the two extra layers (which should be the highest number: i.e. on top of the SEDFLUME layers) can be used by the model to store the active layer and any deposition. Adding these layers ensures that the SEDLFLUME erosion is governed by the SEDLFUME parameters only: i.e. there is no depositional material mixed into the SEDFLUME layers.

Finally, note that SEDFLUME cards only specify erosion rates. The bed porosity and grain size distributions are still specified using the standard AdH/SEDLIB inputs.

For example, the following SEDFLUME cards assign to all nodes and one bed layer (layer 1) SEDFLUME characteristics for two shear stress intervals (0.1 and 0.7 Pa) with two corresponding erosion rates (0.5 kg/m²/s and 1.0 kg/m²/s).

```
MP NSF 2
MP SFA  1  1  0.1  0.5
MP SFA  1  2  0.7  1.0
```

MP NSF

SEDFLUME NUMBER OF SHEAR STRESS INTERVALS SPECIFICATION

1	char	MP	Card type
2	char	NSF	Parameter
3	int	≥ 2	Number of shear stress intervals on the SEDFLUME cards

MP SFN

SEDFLUME EROSION RATES BY NODE

1	char	MP	Card type
2	char	SFN	Parameter
3	int	> 0	The sediment bed layer
4	int	> 0	The node number from which to start
5	int	> 0	The node number at which to end
6	int	> 0	The shear stress interval number
7	real	≥ 0.0	The shear stress corresponding to this interval (Pa)
8	real	≥ 0.0	The erosion rate corresponding to this interval and bed layer ($kg/m^2/s$)

MP SFM

SEDFLUME EROSION RATES BY MATERIAL

1	char	MP	Card type
2	char	SFM	Parameter
3	int	> 0	The sediment bed layer
4	int	> 0	The material type
5	int	> 0	The shear stress interval number
6	real	≥ 0.0	The shear stress corresponding to this interval (Pa)
7	real	≥ 0.0	The erosion rate corresponding to this interval and bed layer ($kg/m^2/s$)

MP SFA

SEDFLUME EROSION RATES FOR ALL NODES

1	char	MP	Card type
2	char	SFA	Parameter
3	int	> 0	The sediment bed layer
4	int	> 0	The shear stress interval number
5	real	≥ 0.0	The shear stress corresponding to this interval (Pa)
6	real	≥ 0.0	The erosion rate corresponding to this interval and bed layer ($kg/m^2/s$)

4.7.2 Sediment Dredging and Placement

Adhv4.7 introduces sediment dredging and placement capability. The user can define multiple dredge and/or placement events. These can occur consecutively or simultaneously. Dredging can consist of discrete events or continuous dredge production. Placement characteristics can be defined by the user, or placement can be associated with a specific dredge event (i.e. one can place the sediment dredged from one location in another location).

To invoke dredge and/or place cards, you define a dredge (**MR DRD**) or place (**MP DRP**) card for EACH dredge or place "event." Each event can be a discrete event (consisting of a defined volume or material to be dredged or placed) or a continuous event (occurring at a prescribed dredge or placement rate over a period of time). Dredge and placement regions are defined by material type. The syntax for these cards are given in the specific card formats later in this manual.

Dredge and placement output are written to a text file, called *Project_name*_dredge_record. The record includes total volume dredged/placed, the porosity of the dredged/placed material, and the fraction of each sediment grain in the dredged/placed material. The file can be easily read into a spreadsheet or other post-processing tool.

The following are some examples of dredge and place cards.

<u>Dredge event 1:</u> Material type 2: discrete event, occurring at time 7200 seconds, dredge to an elevation of -15m

<u>Dredge event 2:</u> Material type 3: continuous dredging from time 0.0 seconds to time 86400 seconds, dredging rate equal to 0.08 m^3/s

<u>Place event 1:</u> Material type 4: place the material dredged in dredge event 1 into material type 4. Do not specify cohesive bed properties (i.e. either there is no cohesive sediment being dredged and placed, or the user is allowing the cohesive properties of the existing bed layer that the material is placed into (in material type 4) to remain unchanged)

MP DRD 1 2 1 7200.0 -15.0
MP DRD 2 3 2 0.0 86400 0.08
MP DRP 1 4 3 1 0

MP DRD

DREDGE AND PLACE: DREDGE CARD

Field	Type	Value	Description
1	char	MP	Card type
2	char	DRD	Parameter
3	int	≥ 1	Dredge Event Identifier
4	int	≥ 1	Material Type to be Dredged
5	int		Type of Dredge Event
		=1	Discrete Event
		=2	Continuous Event

If Event Type = Discrete Event

6	real	any	time at which to initiate dredge event (seconds)
7	real	any	elevation to which to dredge (meters)

If Event Type = Continuous Event

6	real	any	time at which to initiate dredging (seconds)
7	real	any	time at which to stop dredging (seconds)
8	real	any	volumetric rate of dredging (m^3/sec)

MP DRP

DREDGE AND PLACE: PLACEMENT CARD

Field	Type	Value	Description
1	char	MP	Card type
2	char	DRP	Parameter
3	int	≥ 1	Placement Event Identifier
4	int	≥ 1	Material Type where placement will take place
5	int		Type of Placement Event
		=1	Discrete Event
		=2	Continuous Event
		=3	Placement of an associated user-specified dredge event

If Event Type = Discrete Event

6	real	any	time at which to initiate placement event (seconds)
7	real	any	volume of sediment to be placed (m^3)
8	real	0 to 1	porosity of sediment to be placed
9	int		toggle to specify cohesive bed properties
		=0	do not specify cohesive bed properties
		=1	do specify cohesive bed properties

If Field 9 = 0

10	real		grain class fraction of placement for grain 1
.			
.			
.			
NGS+ 10	real		grain class fraction of placement for grain ngs

If Field 9 = 1

10	real		critical shear for erosion for placement
11	real		erosion rate constant for placement
12	real		erosion rate exponent for placement
13	real		grain class fraction of placement for grain 1
.			
.			
.			
NGS+ 13	real		grain class fraction of placement for grain ngs

If Event Type = Continuous Event

6	real	any	time at which to initiate placement event (seconds)
7	real	any	time at which to stop placement (seconds)
8	real	any	volumetric rate of placement (m^3/sec)
9	real	0 to 1	porosity of sediment to be placed
10	int		toggle to specify cohesive bed properties
		=0	do not specify cohesive bed properties
		=1	do specify cohesive bed properties

If Field 10 = 0

11	real		grain class fraction of placement for grain 1
.			
.			
.			
NGS+ 11	real		grain class fraction of placement for grain ngs

If Field 10 = 1

11	real		critical shear for erosion for placement
12	real		erosion rate constant for placement
13	real		erosion rate exponent for placement
14	real		grain class fraction of placement for grain 1
.			

.
.

NGS+ 14	real		grain class fraction of placement for grain ngs

If Event Type = Placement of an associated user specified dredge event

6	int	≥ 1	The associated dredge event to be placed
7	int		toggle to specify cohesive bed properties
		=0	do not specify cohesive bed properties
		=1	do specify cohesive bed properties

If Field 7 = 1

8	real	0 to 1	porosity of sediment to be placed
9	real		critical shear for erosion for placement
10	real		erosion rate constant for placement
11	real		erosion rate exponent for placement
12	real		grain class fraction of placement for grain 1

4.7.3 Bed Consolidation

Cohesive beds will consolidate over time due to self-weight and the weight of the water above. AdH/SEDLIB models that include cohesive constituents can also include bed consolidation, if the user decides to do so. In SEDLIB, the rate of consolidation is specified directly by the user, with a series of parameters. These parameters are defined as a time series, with time 0 equal to the time that the sediment is initially deposited. The parameters are specified similarly to the other bed properties, i.e. by all nodes, by materials, or by selected nodes. An **NP NCP** card is necessary to define the number of time values that will be used to define the consolidation. Then an **MP CPA** (or **CPM**, or **CPN**) card is given for each of the time values with the time in seconds that has elapsed since sediment was deposited, the porosity of the material, the critical shear for erosion, the erosion rate constant, and the erosion rate exponent for the bed material at that time. Hence, the parameters on these cards represent a time history of bed consolidation.

For example, assume we wish to specify consolidation with 3 sets of time parameters. The first parameters correspond to time 0, the second correspond to time 43200 seconds, and the third correspond to time 86400 seconds. The parameters are given below.

MP NCP 3
MP CPA 1 0.0 0.8 0.1 0.02 1
MP CPA 2 43200 0.7 0.5 0.015 1.5

MP CPA 3 86400 0.6 1.0 0.01 2

Note that these values define points in time on a piecewise continuous curve. The values of each of these parameters are interpolated from this curve to compute the appropriate values for the elapsed model time, at every time step.

Note also that the porosity grows smaller through time. This is how the consolidation occurs.

MP NCP

CONSOLIDATION TIME SERIES SPECIFICATION

1	char	MP	Card type
2	char	NCP	Parameter
3	int	≥ 0	Number of time values in the consolidation time series for sediment transport

MP CPN

CONSOLIDATION TIME SERIES PROPERTIES APPLIED TO SELECTED NODES

1	char	MP	Card type
2	char	CPN	Parameter
3	int	> 0	The node number from which to start
4	int	> 0	The node number at which to end
5	int	> 0	Consolidation time value number
6	real	≥ 0.0	Elapsed time since sediment deposition (sec)
7	real	≥ 0.0	The porosity at the elapsed time
8	real	≥ 0.0	The critical shear stress for erosion at the elapsed time
9	real	≥ 0.0	The erosion rate constant at the elapsed time
10	real	≥ 0.0	The erosion rate exponent at the elapsed time

MP CPM

CONSOLIDATION TIME SERIES PROPERTIES APPLIED BY MATERIAL

1	char	MP	Card type
2	char	CPM	Parameter
3	int	> 0	Material type ID number
4	int	> 0	Consolidation time value number
5	real	≥ 0.0	Elapsed time since sediment deposition (sec)
6	real	≥ 0.0	The porosity at the elapsed time
7	real	≥ 0.0	The critical shear stress for erosion at the elapsed time
8	real	≥ 0.0	The erosion rate constant at the elapsed time
9	real	≥ 0.0	The erosion rate exponent at the elapsed time

MP CPA

CONSOLIDATION TIME SERIES PROPERTIES APPLIED FOR ALL NODES

1	char	MP	Card type
2	char	CPA	Parameter
3	int	> 0	Consolidation time value number
4	real	≥ 0.0	Elapsed time since sediment deposition (sec)
5	real	≥ 0.0	The porosity at the elapsed time
6	real	≥ 0.0	The critical shear stress for erosion at the elapsed time
7	real	≥ 0.0	The erosion rate constant at the elapsed time
8	real	≥ 0.0	The erosion rate exponent at the elapsed time

4.7.4 No Bed Displacement by Material Type

Often, it is neither necessary, nor desirable, to compute bed displacements at every point in the model domain. For example, at the inflow boundary, the inherent uncertainty in the inflowing sediment concentration can result in large perturbations of the bed displacement, which in turn can contribute to model instability (due to the feedback of these changes to the hydrodynamics).

The **MP NDM** card allows the user to turn off bed displacements for selected material types. This card requires the material number to be specified. For material types with an **NDM** card active, sediment can be eroded from the bed or deposited to the bed, but the bed elevation will not change.

There are 2 different options used to enable no bed displacement, which are specified by the user with a 0 or a 1 on the **NDM** card.

<u>Option 0:</u> The bed displacement at each time step is transferred from the bed surface to the bottom of the deepest bed layer. This ensures that sediment bed mass is conserved, but the elevation of the bed surface remains constant. However, this also means that the elevation of the solid boundary (i.e. bed surface elevation minus the total bed thickness) will change in response to erosion or deposition of the bed. This can create problems if the elevation of the solid boundary is important (i.e. if the location is on top of a dike structure). Hence, option 0 is most useful for parts of the model domain where the solid boundary elevation is not important (such as at an inflow boundary, or in a floodplain adjacent to a river).

<u>Option 1:</u> Neither the bed surface elevation nor the solid boundary elevation is allowed to change. Eroded and/or deposited sediment thickness at the surface is replaced by an equivalent thickness of sediment added to or taken away from the deepest bed layer(s).

This means that neither the bed surface nor the solid boundary can move during the simulation, but it also means that sediment mass is not conserved (because sediment is just added to or taken away from the bed in response to erosion and deposition at the bed surface). Because it is not mass conservative, this option is intended for *model initiation only*. It is very useful as a means to initialize the sediment bed surface gradation throughout the domain.

MP NDM

TURN OFF DISPLACEMENT BY MATERIAL TYPE

1	char	MP	Card type
2	char	NDM	Parameter
3	int	> 0	Material type ID number
4	int	0 or 1	Select type of NDM implementation 0 = bed sediment mass is preserved, bed surface elevation is fixed, solid bottom changes elevation 1 = bed sediment mass is not preserved, bed surface elevation is fixed, solid bottom elevation is fixed

4.7.5 Approximation of Local Scour

Very close to structures and hard points, abrupt changes in geometry and/or bathymetry can result in locally generated vertical circulation cells and other non-hydrostatic flows. These can induce the formation of local scour holes.

The hydrostatic approximation associated with the shallow water version of AdH precludes direct simulation of these scour holes. Rather, the hydrostatic approximation will tend to result in a modeled flow condition that is more generally depositional that erosional. Hence, the model has a tendency to fill existing scour holes with sediment, and introduced structures have a tendency not to exhibit local scour in the model.

Since AdH is not intended to simulate local scour, but rather is intended to examine sediment transport conditions away from these local phenomena (such as the influence of existing and introduced structures on nearby and regional bathymetry) this is not a crucially significant problem. However, the tendency for AdH to fill and/or not generate local scour conditions around structures may influence the interaction of the structure with the flow, and this in turn could influence the ability of the model to simulate the influence of the structure on the nearby bathymetry.

To help address this problem, AdH has been equipped with a local scour card. The **MP LSM** card allows the user to define local scour conditions for specific material type(s).

The local scour conditions are modeled simply as scour-only conditions: that is, no deposition is permitted for that material type.

There are 2 different options used to enable local scour, which are specified by the user with a 0 or a 1 on the **LSM** card.

Option 0: The local scour conditions are modeled simply as scour-only conditions: that is, no deposition is permitted for that material type.

Option 1: The local scour conditions are modeled by applying a scale factor that is applied to the ambient shear stress. The scale factor is provided by the user on the **LSM** card. For example, a value of 2 would cause the bed shear stress for the material type where the **LSM** card is applied to be 2 times larger than that which is computed from the physics in the model.

The user is responsible for defining the geometry of the scour holes (by selecting elements to be added to the local scour material type(s)). Also, the user must be constantly cognizant of the fact that the local scour card is an ***approximate*** method. It creates scour holes where the user says they should be: it does not create them for the physically correct reasons, and it does not place them where the model physics says they should go.

Hence, this method can be useful for sustaining and or creating qualitative approximate scour hole morphology, which in turn can allow for more physically realistic interaction between structures and the flow field. But care and judgement must be exercised by the modeler to ensure that the method is applied appropriately.

MP LSM

LOCAL SCOUR BY MATERIAL TYPE

1	char	MP	Card type
2	char	NDM	Parameter
3	int	> 0	Material type ID number
4	int	0 or 1	Select type of LSM implementation 0 = no deposition is permitted 1 = shear stress is scaled by the quantity given in 5
5	real	>0	(only read if quantity 4 (above) =1) scale factor for bed shear stress (e.g. 2 means that the shear stress is multiplied by 2)

4.7.6 Infiltration of Fine Sediment into Coarse Sediment Beds

For coarse sediment beds (such as gravel beds), the deposition of fine sands and silts can sometimes form a top layer, and can sometimes infiltrate though the gravel bed to fill up the pore spaces within the gravel matrix. The ability to predict which of these behaviors is manifested for a given gravel bed can be important for many different considerations, including, for example, salmonid spawning.

The results of recent research by Gibson et al. (2010) established criteria for estimating the threshold for determining whether or not the deposited sediment will “bridge” (for a top layer) or “percolate” (infiltrate into the bed). These criteria have been included in SEDLIB using the following equation.

$$\frac{d_{05.Bed}}{d_{85.Deposit}} = 12\beta \qquad (6)$$

Where $d_{05.\mathrm{Bed}}$ is the 5% finer diameter of the existing bed material (i.e. diameter that 5% of the existing bed material is finer than) ,$d_{85.\mathrm{Deposit}}$ is the 85% finer diameter of the newly deposited material (i.e. the diameter that 85% of the newly deposited materal is finer than), and β is a user specified multiplier (default = 1.0).

If the $d_{05.\mathrm{Bed}}/ d_{85.\mathrm{Deposit}}$ ratio is less than 12 β, the deposit will “bridge”, and form a new layer. If the $d_{05.\mathrm{Bed}}/ d_{85.\mathrm{Deposit}}$ ratio is greater than 12 β, the deposit will infiltrate into the existing bed and fill the pore spaces.

If the user desires to invoke this option, the **SP SIF** card must be used. The only additional information supplied by the user is the value of β, which should initially be set equal to 1, and only adjusted if site specific information is available that would justify altering it.

SP SIF

SEDIMENT PROCESS: SEDIMENT INFILRATION FACTOR

Field	Type	Value	Description
1	char	SP	Card type
2	char	SIF	Parameter
3	real	> 0	coefficient to adjust the sediment infiltration factor computation (default is 1)

4.7.7 Sediment Diversion Features

Two features have been added to the code to facilitate the modeling of sediment transport where river diversions are present. River diversions can be controlled (i.e. with a structure) or uncontrolled. They can also be designed to capture various strata of the water column (e.g. skimming flow or deep water withdrawal).

Water and sediment withdrawal at controlled diversions can be modeled with discharge (**DIS**) and velocity (**OVL**) cards, if the user is not concerned with reintroducing the diverted sediment elsewhere in the same model domain.. If the user is concerned with reintroducing the diverted sediment elsewhere in the same model domain, an **OUT** card can be used. The model will calculate the mass of sediment extracted at an **OUT** card, and transfer that sediment mass to the discharge associated with a specified inflow string. See the adh hydrodynamic manual for guidance on how to use DIS, OVL and OUT cards.

In order to directly model the influence of selective withdrawal from targeted strata in the water column, it would be necessary to perform hi-fidelity 3D numerical modeling. However, the processes can be approximated with a sediment diversion adjustment factor that is equal to the fraction of the sediment flux that is associated with a user defined segment of the water column. This adjustment factor can be used as a calibration parameter, within reasonable limits, to adjust the diversion to match observed sediment capture characteristics.

The sediment diversion adjustment factor is applied using the **SDV** card. The card references a user-defined mid string (**MDS**) or edge string (**EGS**) string that is defined across the diversion entrance. The sediment flux across this string is then adjusted, according to the user specifications of the portion of the water column to be captured.

SDV

SEDIMENT DIVERSION ADJUSTMENT

Field	Type	Value	Description
1	char	SDV	Card type
2	int	≥ 1	MDS or EGS String ID number (node)
4	int	≥ 1	The top elevation of the zone of withdrawal (an elevation greater than the local water surface elevation will be set equal to the local water surface elevation
4	int	≥ 1	The bottom elevation of the zone of withdrawal (an elevation less than the local bed elevation will be set equal to the local bed elevation
4	int	≥ 1	The bottom elevation of the main channel (i.e. the

river being diverted from) (an elevation less than the local bed elevation will be set equal to the local bed elevation

5 Sediment Processes

The sediment process cards are designed to allow the user to select among various methods of describing a specific process. SedLib has several process options available and intends to grow as additional options are necessary or requested. Processes included to date are:

- cohesive settling
- wind wave shear
- noncohesive suspended entrainment
- noncohesive bedload entrainment
- noncohesive hiding factor

These process cards all begin with **SP** and are followed by a three letter descriptor of the specific process being specified. The third field is a flag indicating which process algorithm to use. Since some methods require additional parameters, the fields 4 and above are reserved for any parameter that may be required for a specific method.

Sediment Process cards

SP CSV

SEDIMENT PROCESS: COHESIVE SETTLING VELOCITY

Field	Type	Value	Description
1	char	SP	Card type
2	char	CSV	Parameter
3	int	= 0	0 - Free Settling
		= 1	1 - Hwang and Mehta
4…	real	≥ 0	Process specific parameter(s)

SP WWS

SEDIMENT PROCESS: WIND WAVE SHEAR

Field	Type	Value	Description
1	char	SP	Card type
2	char	WWS	Parameter
3	int	= 0	0 – No applied wind-wave stress
		= 1	1 - Grant and Madsen
		= 2	2 - Teeter
4…	real	≥ 0.0	Process specific parameter(s)

SP NSE

SEDIMENT PROCESS: NONCOHESIVE SUSPENDED ENTRAINMENT

Field	Type	Value	Description
1	char	SP	Card type
2	char	NSE	Parameter
3	int	= -1	-1 – No suspended load (bedload only)
		= 0	0 - Garcia-Parker
		= 1	1 - Wright-Parker
		= 2	2 – Van Rijn
		= 3	3– Yang (should be run with SP NBE = -1)
4…	real	≥ 0.0	Process specific parameter(s)

SP NBE

SEDIMENT PROCESS: NONCOHESIVE BEDLOAD ENTRAINMENT

Field	Type	Value	Description
1	char	SP	Card type
2	char	NSE	Parameter
3	int	= -1	-1 – No bedload (suspended load only)
		= 0	0 - Garcia-Parker
		= 1	1 – Meyer Peter Mueller
		= 2	2 – Meyer Peter Mueller with Wong Parker Correction
		= 3	3 – Wilcock (should be run with SP NSE = -1)
4…	real	≥ 0.0	Process specific parameter(s)
For **Wilcock (option 3)**, there are 2 of these:			
4	real	≥ 0.0	critical shear stress for sand
5	real	≥ 0.0	critical shear stress for gravel

SP HID

SEDIMENT PROCESS: NONCOHESIVE HIDING FACTOR

Field	Type	Value	Description
1	char	SP	Card type
2	char	NSE	Parameter
3	int	= 0	0 – Karim Holly Yang
		= 1	1 – Egiazaroff
		= 2	2 – Wu Wang Jia
		= 3	3 – Parker and Klingeman
4…	real	≥ 0.0	Process specific parameter(s)

For **Parker and Klingeman (option 3)**, there is 1 of these:

4	real	1≥ X≥ 0.0	hiding factor exponent

6 Coupled Vegetation Modeling: SEDLIB-VEG

Natural multi-year or multi-decadal cycles that are associated with riverine, lacustrine or estuarine systems include the introduction, growth, and/or loss of vegetation. This may include wetland vegetation, riparian woody vegetation (trees), or other vegetated environments.

The growth and/or loss of vegetation can have several different potential influences on the hydrodynamics and morphodynamics of these systems. These include

- Changes to hydrodynamic drag, influencing preferential flow pathways
- Changes to the erodability of the substrate (e.g. vegetated emergent features are much more resistant to erosion than barren emergent features)
- Changes to the rate of subsidence/elevation-gain. The accumulation of refractory (residual) organics associated with vegetation senescence adds elevation to marsh surfaces. For mature marshes, this is the primary mechanism of elevation gain, and hence the primary mechanism whereby the marsh maintains planform elevation when subjected to relative sea-level rise.
- Changes to the ability for features to trap sediment. Vegetated features tend to sequester more fine sediments than barren features.
- Changes in the ability for wind-wave erosion to resuspend settled sediments. Vegetation shelters sediments from wind-wave erosion, by mitigating the propagation of wind-wave energy into the marsh interior.

To simulate the effects of vegetation on hydrodynamic and sediment transport simulations, a vegetation module has been added to SEDLIB. This module, called SEDLIB-VEG, was added to SEDLIB (as opposed to being developed as a separate module) so that the interactions between existing bed sediments, newly settled and/or eroded sediment, and vegetation root and refractory material can be solved simultaneously within one computational framework. This permits the effects associated with various time scales, ranging from seasonal and annual pheonoema, to discrete, rapid changes associated with significant events (such as a large storm or a sediment placement), to be simulated for both inorganic sediments and for the vegetation (roots and refractory organics) simultaneously.

The model is integrated into the SEDLIB sediment module by simply adding 2 additional fine sediment classes to a given AdH simulation, and assigning these fine sediment classes to be organic classes. The first is the root class: it represents the behavior of the root material. The second is the refractory class: it represents the storage of compacted refractory material.

The root material class is assigned a very high porosity, commensurate with the porosity of the rooting zone. The refractory class is assigned a somewhat lower porosity, associated with compacted refractory organics (note that this module does not do compaction of the refractory organics: it assumes that the refractory fractions of both litterfall and root decay are immediately compacted).

The only difference between these organic "sediment" classes and the other inorganic classes is that the masses of each of these classes are modified at each time step as a result of vegetative growth and decay.

SEDLIB-VEG utilizes user-provided coefficients and local hydrodynamic conditions to generate root mass. The mass of shoots (vegetation) is computed as a function of the root mass. A fraction of the roots and shoots is lost to senescence, and a fraction of this material is retained as refractory organic material. The accumulation of root mass and refractory organics, represented by the two selected "sediment" grains, results in added elevation to the bed surface.

SEDLIB-VEG is dynamically linked to the hydrodynamics by continuously modifying the vegetative friction as a function of the computed vegetative mass. This is done as follows:

- The computed vegetation density is associated with increased vegetation drag. Typically, a **FR URV** or **FR EDO** card is used to assign vegetative friction. These cards include losses to the vegetated stems, and losses due to the undergrowth (or barren substrate).
- When SEDLIB-VEG is invoked, the vegetation density fraction at that time step is computed. This vegetation density fraction is equal to the ratio of the actual vegetation mass to the equilibrium vegetation mass provided by the user on the VEG card.
- The actual friction at that time step is then computed as the undergrowth loss (or barren substrate) value plus the vegetated stems loss value times the vegetation density fraction computed above.
- In this way, the vegetated friction is always computed as a function of the actual density of vegetation at any given time step.

More details on the theoretical basis, the basic equations, and the user-proved coefficients necessary to run SEDLIB-VEG are given in Appendix A.

To invoke SEDLIB-VEG in AdH, it is necessary to do the following.

1. Add 2 extra fine grain classes. These will be used as organic classes for SEDLIB-VEG. These also assign the physical properties and erosional characteristics of the roots and refractory sediments (note that, once eroded, the SEDLIB-VEG model assumes that the organic material disappears. There is no transport or deposition of organics modeled in SEDLIB-VEG)
2. Assign **FR URV** or **FR EDO** cards to the material types where vegetation is expected to grow.
3. Add a **VEG** card to the input deck, to assign the selected fine sediment classes to the roots and refractory organics, and the global values of the vegetation growth properties.
4. Add **MP VGM** cards if you desire to modify or turn off vegetation on selected material types.

An example is given below.

The vegetation model is to be invoked for material type 2 only, for a model that is simulating 12 inorganic sediment classes (5 cohesive classes and 7 cohesionless classes). The model has two total material types (1 and 2) so the vegetation will be defined globally, and then turned off on material type 1 so that only material type 2 can grow vegetation.

1. Two additional grain classes are added to the model. These are used to characterize the specific gravity, porosity, and erosional characteristics of the two organic classes used to define the vegetation roots and refractory organics. The two new classes are highlighted below.

   CN CLA 1 1 0.000003 2.65 0.68 .5 0.01 0.005 0.000009 "CLAY"
   CN CLA 2 1 0.000006 2.65 0.68 .5 0.01 0.01 0.000036 "VFM"
   CN CLA 3 1 0.000011 2.65 0.68 .5 0.01 0.02 0.000121 "FM"
   CN CLA 4 1 0.000023 2.65 0.68 .5 0.01 0.04 0.000529 "MM"
   CN CLA 5 1 0.000045 2.65 0.68 .5 0.01 0.075 0.002025 "CM"
   CN SND 6 1 0.000088 2.65 0.35 "VFS"
   CN SND 7 1 0.000177 2.65 0.35 "FS"
   CN SND 8 1 0.000354 2.65 0.35 "MS"
   CN SND 9 1 0.000707 2.65 0.35 "CS"
   CN SND 10 1 0.001410 2.65 0.35 "VCS"
   CN SND 11 1 0.002830 2.65 0.35 "VFG"
   CN SND 12 1 0.005660 2.65 0.35 "FG"
   CN CLA 13 1 0.00001 1.3 0.98 1.0 0.02 0.005 0.000036 "ROOTS"

CN CLA 14 1 0.00002 1.6 0.90 1.0 0.02 0.005 0.000036 "REFRACTORY"

2. A emergent vegetation roughness type (either **FR URV** or **FR EDO**) is used to define the roughness characteristics of material type 2. When no vegetation is present, the undergrowth roughness height (in this example, 0.02) defines the roughness. When vegetation is present, the drag associated with the vegetation is added, in proportion to the modeled vegetation density.

   FR URV 2 0.02 0.01 50

3. A **VEG** card is added to associate grains 13 and 14 with roots and refractory sediments, respectively. It also assigns global vegetation growth properties. Note that the card invokes XY1 series 4, so that the equilibrium mass of vegetation can be entered as a time series. This permits temporal (seasonal) adjustment of vegetation growth rate. A description of this card is given at the end of this chapter.

   VEG 13 14 4e-8 0.2 4 3.0 1.0 0.1

   XY1 4 3 2 0
   0 0.1
   4344 1.6
   8760 0.1

4. A **MP VGM** card is added to ensure that there is no growth for material type 1. This is easily done by setting the rate of wetland vegetation growth equal to 0. Note that one can also use the **MP VGM** card to assign different vegetation characteristics, to permit the growth of various dominant species in the same model domain. A description of this card is given at the end of this chapter.

   MP VGM 1 0.0 0.2 4 3.0 1.0 0.1

Note that, since the root and refractory classes are just additional sediment classes, the standard output files associated with bed properties contain all the run-time information for these properties. For example, the total mass of root material in the bed can be found in the *_smr.dat file, in the column that corresponds to the root material (for the example above, column 13). Since the root and vegetation mass are linked by the user-specific root-to-shoot ratio, this information can also be used to investigate the vegetation coverage.

VEG

SEDLIB-VEG: GLOBAL PARAMETERS

Field	Type	Value	Description
1	char	VEG	Card type
2	int	≥ 1	The constituent assigned to represent organic root mass
3	int	≥ 1	The constituent assigned to represent refractory organic mass
4	real	≥ 0.0	the rate of wetland vegetation growth (M $L^{-2}T^{-1}$)
5	real	≥ 0.0	the limiting depth (L): the maximum water depth for which wetland vegetation will grow.
6	int	≥ 1	The XY1 series used to define the equilibrium mass per unit area of vegetation (ML^{-2}): this is the mass for which vegetation mortality is equal to vegetation growth.
7	real	≥ 0.0	the root-to-shoot ratio: this is the ratio of root mass to wetland vegetation mass.
8	real	≥ 0.0	the rooting thickness limit (L): this is the maximum distance below the surface of the sediment bed where roots can be found.
9	real	≥ 0.0	the labile fraction: the fraction of dead vegetative material that decays quickly.

MP VGM

SEDLIB-VEG: PARAMETERS BY MATERIAL TYPE

Field	Type	Value	Description
1	char	MP	Card type
2	char	VGM	Card type
3	int	≥ 1	The material type
4	real	≥ 0.0	the rate of wetland vegetation growth (M $L^{-2}T^{-1}$)
5	real	≥ 0.0	the limiting depth (L): the maximum water depth for which wetland vegetation will grow.
6	int	≥ 1	The XY1 series used to define the equilibrium mass per unit area of vegetation (ML^{-2}): this is the mass for which vegetation mortality is equal to vegetation growth.
7	real	≥ 0.0	the root-to-shoot ratio: this is the ratio of root mass to wetland vegetation mass.
8	real	≥ 0.0	the rooting thickness limit (L): this is the maximum distance below the surface of the sediment bed where roots can be found.
9	real	≥ 0.0	the labile fraction: the fraction of dead vegetative material that decays quickly.

7 Running AdH

Running AdH for sediment is no different that running it for hydrodynamics. Once the three required files have been created, pre_AdH is run and it creates the necessary input file for AdH. Then the AdH model is run. The commands are:

pre_adh filename
adh filename

where *filename* is the root of the model's filenames, i.e. for a model named pl8_AdH the following three files would be required pl8_AdH.3dm, pl8_AdH.hot and pl8_AdH.bc. All three files must have the same *filename* as their root followed by one of three suffixes.

The standard output for AdH is in a tab delimited format so that it can be manipulated by the user in many different ways. The first column of data gives the physics being solved for that iteration. For hydrodynamics the physics is listed as **HYD** and for transport it is listed as **TRN**. When modeling sediment each suspended load and bed load iteration is listed as **SLT** and **BLT**, respectively. The order of the data in the short column tabular form (**PC LVL** 0) from left to right is physics being solved, time, time step size, percent completion progress, nonlinear iteration number, linear iteration count, node number giving the maximum residual, node number giving the maximum increment norm, node count after adaption, failure flag. The order of the data in the long column tabular form (**PC LVL** 1) from left to right is physics, time, time step size, percent completion progress, nonlinear iteration number, linear iteration count, maximum residual norm, node number giving the maximum residual, x, y, and z-coordinates of this worst node, maximum increment norm, node number giving this maximum increment, x, y, and z-coordinates of this worst node, node count after adaption, failure flag. All time values in the screen output are in seconds. The maximum residual norm is used to determine convergence against the **NTL** value. The maximum increment norm is used to determine convergence against the **ITL** value, if included in the boundary conditions file. If no adaption is taking place, the node count after adaption will not change throughout the run. The failure flag is the # symbol and indicates that convergence did not occur and the time step will be cut to ¼ the previous value. This column is left empty in all other instances. For transport iterations, the same information is provided but preceded by a line indicating that the data to follow is from the transport computations.

After the model is run, GMS or SMS can be used to visualize the results. The depth, velocity, and error files are the minimum output files that will be produced in any simulation. Sediment simulations will include concentration output, bed layer output, and bed displacement output. Other output files will be generated depending on the options requested in the boundary conditions file.

Output filename conventions (*.dat)

*_con#.dat	constituent concentration, # = constituent number (scalar, parts per million by mass for sediment), suspended sediment profile factor+, bedload mass per unit area
*err_con#.dat	non-normalized residual error for the transport constituent (scalar)
*_bed_dpl.dat	sediment bed displacement (scalar, meters)
*_alt.dat	active layer thickness (scalar, meters)
*_ald.dat	active layer distribution (scalar, one column for each grain class)
*_blt#.dat	bed layer thickness, # = layer number (scalar, meters, 1 is the bottom-most layer)
*_bld#.dat	bed layer distribution, # = layer number (scalar, 1 is the bottom-most layer, one column for each grain class)
*_cbp#.dat	cohesive bed property, # = layer number (scalar, 1 is the bottom-most layer, one column for each cohesive property)
*_bsh.dat	bed shear stress magnitude (scalar, Pa)
*_smr.dat	sediment mass residual: the total mass of each sediment grain in the bed (kg/m^2, one column for each grain class)
*_bedload.dat	Bedload flux, cumulative value for all grains (vector, kg/m/s)
*_susload.dat	suspended load flux, cumulative value for all grains (vector, kg/m/s)
*_belev.dat	breach bed elevation (scalar, length)
*_conflx	concentration flux across a string for each constituent is included when the FLX card is used followed by the string number. This is NOT an SMS file (flux is in kg/sec). It is designed to be easily opened in a spreadsheet or other post-processor.
*_tflx	hydrodynamic flux across a string is included when the FLX card is used followed by the string number. This is NOT an SMS file (flux is in m/sec). It is designed to be easily opened in a spreadsheet or other post-processor.

*_dredge_record	a record of each dredge and placement event is written if any MP DRD or MP DPR cards are present. The record includes total volume dredged/placed, the porosity of the dredged/placed material, and the fraction of each sediment grain in the dredged/placed material. This is NOT an SMS file. It is designed to be easily opened in a spreadsheet or other post-processor.

For a 3-constituent simulation (1 non-sediment constituent and 2 sediment constituents) of 2 grains and 3 bed layers, the sediments are constituent 2 and 3, the output files would be: (information in parenthesis gives names for the hotstart file)

*_dep.dat (ioh)	Depth value
*_ovl.dat (iov)	X_vel, Y_vel, Z_vel (Z_vel = 0 for 2D)
*_err.dat	Residual error
*_err_hydro.dat	Hydro residual error
*_con1.dat (icon 1)	Concentration 1
*_con2.dat (icon 2)	Concentration 2, Rouse factor+, bedload mass per unit area
*_con3.dat (icon 3)	Concentration 3, Rouse factor+, bedload mass per unit area
*_err_con1.dat	Transport residual error for transport 1
*_err_con2.dat	Transport residual error for transport 2
*_err_con3.dat	Transport residual error for transport 3
*_bed_dpl.dat (ibd)	Sediment bed displacement
*_alt.dat (ialt)	Active layer thickness
*_ald.dat (iald)	Ald-grain1, Ald-grain2
*_blt1.dat (iblt 1)	Bed layer thickness
*_blt2.dat (iblt 2)	Bed layer thickness
*_blt3.dat (iblt 3)	Bed layer thickness
*_bld1.dat (ibld 1)	Bld-grain1, Bld-grain2
*_bld2.dat (ibld 2)	Bld-grain1, Bld-grain2
*_bld3.dat (ibld 3)	Bld-grain1, Bld-grain2
*_bsh.dat	Bed shear magnitude
*_smr.dat	Sediment mass residual grain 1, grain 2
*_bedload.dat	Bedload_X, Bedload_Y
*_susload.dat	Suspended load X, Suspended load Y

+Suspended sediment profile factor is the ratio of the near-bed concentration to the depth-averaged concentration.

8 References

Alishahi, M.R., and Krone, R.B. .1964. "Suspension of cohesive sediments by wind-generated waves," *Technical Report HEL-2-9*, Hydraulic Engineering Laboratory, University of California, Berkeley.

Gibson, S. A., D. Abraham, R. Heath, and D. Schoellhamer (2010), Bridge formation threshold for sediment infiltrating into a coarse substrate, ASCE J. Geotech. Eng., 136(2), 402–406

Heath, R. E., G. L. Brown, C. D. Little, T. C. Pratt, J. J. Ratcliff, D. Abraham, D. W. Perkey, N. B. Ganesh, S. K. Martin, and D. P. May. 2015. *Old River Control Complex Sedimentation Investigation*. ERDC/CHL TR-15-8. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

McNeil, Joe, Catherine Taylor, and Wilbert Lick. 1996. "Measurements of Erosion of Undisturbed Bottom Sediments with Depth." Journal of Hydraulic Engineering 122(6): 316–324.

Savant, Gaurav, Berger Charlie, McAlpin, Tate O., and Jennifer N. Tate. "Efficient Implicit Finite-Element Hydrodynamic Model for Dam and Levee Breach." *Journal of Hydraulic Engineering*. 137, 1005 (2011); doi:10.1061/(ASCE)HY.1943-7900.0000372

Savant et al. 2020

Sharp, J. A., C. D. Little, G. L. Brown, T. C. Pratt, R. E. Heath, L. C. Hubbard, F. Pinkard, S. K. Martin, N. D. Clifton, D. W. Perkey, and N. B. Ganesh. 2013. *West Bay Sediment Diversion Effects*. ERDC/CHL TR-13-15. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Tate, Jennifer N, R. C. Berger, and Richard L. Stockstill, (2006) "Refinement indicator for mesh adaptation in shallow-water modeling". Journal of Hydraulic Engineering 2006; 132:854–857.

Tate, J. N., J. P. McKinney, T. C. Pratt, F. C. Carson, M. W. Tubman, G. L. Brown, K. M. Barry, R. T. McAdory, and M. J. Briggs. 2009. *Salinas de San Pedro (Cabrillo) Wetland Restoration Project. Volume 1, Main Text*. ERDC/CHL TR-09-14. Vicksburg, MS: U.S. Army Engineer Research and Development Center

Tate, J.N., R.C. Berger, and C.G. Ross. "Houston-Galveston Navigation Channels, Texas Project – Navigation Channel Sedimentation Study, Phase 2." ERDC/CHL 08-8, July 2008. U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Tate, Jennifer N., Gaurav Savant, and Darla C. McVan. (2012) "Rapid Response Numerical Modeling of the 2010 Pakistan Flooding." *ASCE Journal of Leadership and Management in Engineering*. October 2012.

Teeter, Allen Michael (2002) "Sediment Transport in Wind-Exposed Shallow, Vegetated Aquatic Systems" A Dissertation. Louisiana State University.

Wu, Jin (1982). "Wind-Stress Coefficients Over Sea Surface From Breeze to Hurricane" *Journal of Geophysical Research,* Vol 87, No. C12, November 1982, pp 9704-9706.

Appendix A: SEDLIB-VEG Theoretical Development

Introduction

This is model is based largely on the work of Fagherazzi et al (2012). The primary differences between this model and the referenced model arise from the fact that this model is being incorporated into an existing sediment model (SEDLIB), so it must make computations that are dependent on local, near-instantaneous conditions (e.g. water depth).

The model is integrated into the SEDLIB sediment module by simply assigning 2 of the sediment classes to be organic classes. The first is the root class: it represents the behavior of the root material. The second in the refractory class: it represents the storage of compacted refractory material.

The root material class is assigned a very low bulk density, commensurate with the bulk density of the rooting zone. The refractory class is assigned a higher bulk density, associated with compacted refractory organics (note that this module does not do compaction: it assumes that the refractory fractions of both litterfall and root decay are immediately compacted).

The only difference between these organic "sediment" classes and the other inorganic classes is that the masses of each of these classes are modified at each time step as a result of vegetative growth and decay.

Primary Productivity Module Algorithm for Wetland Vegetation

The equation for the mass of wetland vegetation at a given time step is given as a basic implicit source/sink mass balance:

$$m_{veg} = \frac{m_{veg.o} + v_{src}\Delta t}{1 + v_{snk}\Delta t} \qquad 1$$

The source term is given as a function of local, instantaneous depth:

$$v_{src} = v_{src.m}\left(1 - \frac{h}{h_{ldep}}\right) : 0 \le h \le h_{ldep} \qquad 2$$

The sink term is found by setting m_{veg} and $m_{veg.o}$ equal to $m_{veg.eq}$ in (1) and solving for v_{snk}.

$$v_{snk} = \frac{v_{src.m}}{m_{veg.eq}} \qquad 3$$

Once m_{veg} has been determined, m_{root} is given as a simple function of the root-to-shoot ratio.

$$m_{root} = m_{veg} r_{rs} \qquad 4$$

The refractory mass is a cumulative mass. It is updated at each time step with the contribution of both de-caying vegetation and decaying roots, less the labile material.

$$m_{refr} = m_{refr.o} + m_{veg}\left(1 + r_{rs}\right) v_{snk} \Delta t \left(1 - f_{lab}\right) \qquad 5$$

Integration of Organics into the Sediment Bed

The root mass and the refractory source term are applied in the sediment layers immediately beneath the bed surface. The root mass is assumed to decay exponentially, from a maximum value at the surface, to a (near) zero value at a user defined limiting root thickness (t_{rl}).

The mass added to each bed layer is used to adjust the bed layer thickness. The bed layer thickness of each sediment bed layer is given by the following equation:

$$T_L = \frac{m_L}{\rho s_S (1 - p_L)} \qquad 6$$

Where T_L is the thickness of the layer, ρ is the density of water, s_S is the specific gravity of the sediment, and p_L is the porosity of the layer.

To add thickness, therefore, it is only necessary to add mass according to 6. i.e.;

$$\Delta T_L = \frac{\Delta m_{refr}}{\rho s_{refr} (1 - p_{refr})} \qquad 7$$

Where s_S and p_L are the specific gravity and the porosity of the added refractory organics.

Figure 1 demonstrates how the addition of root mass and refractory organic mass to the bed layers results in the change in bed surface elevation.

Figure 1: Demonstration of Bed Elevation Change due to Organic Mass Production Associated with Wetland Vegetation.

Each of the terms used in this development are defined below. Terms with an asterisk are user-defined terms.

f_{lab}* = the labile fraction: the fraction of dead vegetative material that decays quickly.
h_{ldep}* = the limiting depth (L): the maximum water depth for which wetland vegetation will grow.
m_{refr} = the mass per unit area of the refractory organic material in the sediment bed (ML^{-2})
$m_{refr.o}$ = the mass per unit area of the refractory organic material in the sediment bed at the previous time step (ML^{-2})
m_{root} = the root mass per unit area in the sediment bed (ML^{-2})
m_{veg} = the mass per unit area of wetland vegetation (ML^{-2})
$m_{veg.eq}$* = the equilibrium mass per unit area of vegetation (ML^{-2}): this is the mass for which vegetation mortality is equal to vegetation growth.
$m_{veg.o}$ = the mass per unit area of wetland vegetation at the previous time step (ML^{-2})
r_{rs}* = the root-to-shoot ratio: this is the ratio of root mass to wetland vegetation mass.
t_{rl}* = the rooting thickness limit (L): this is the maximum distance below the surface of the sediment bed where roots can be found.
Δt = the time step (T)
v_{snk} = the rate of wetland vegetation mortality ($M\ L^{-2}T^{-1}$)
v_{src} = the rate of wetland vegetation growth ($M\ L^{-2}T^{-1}$)
$v_{src.m}$* = the maximum rate of wetland vegetation growth ($M\ L^{-2}T^{-1}$)

Demonstration

Figure 2 demonstrates how the wetland vegetation model works. The sediment bed is subjected to a tidal signal, with a mean elevation that increases over time (simulating a sea level rise rate that exceeds the maximum rate of marsh accretion). Initially, as the marsh inundates, the vegetation grows until it reaches a maximum (where growth and mortality are in balance). The root mass associated with this vegetation increases the bed elevation. Decaying vegetation is added to the refractory mass, further increasing the bed elevation over time.

As the tide range increases further, the mortality exceeds the rate of growth and the vegetation mass is reduced. Eventually, all organic production ceases as the threshold depth for growth his exceeded for all phases of the tide.

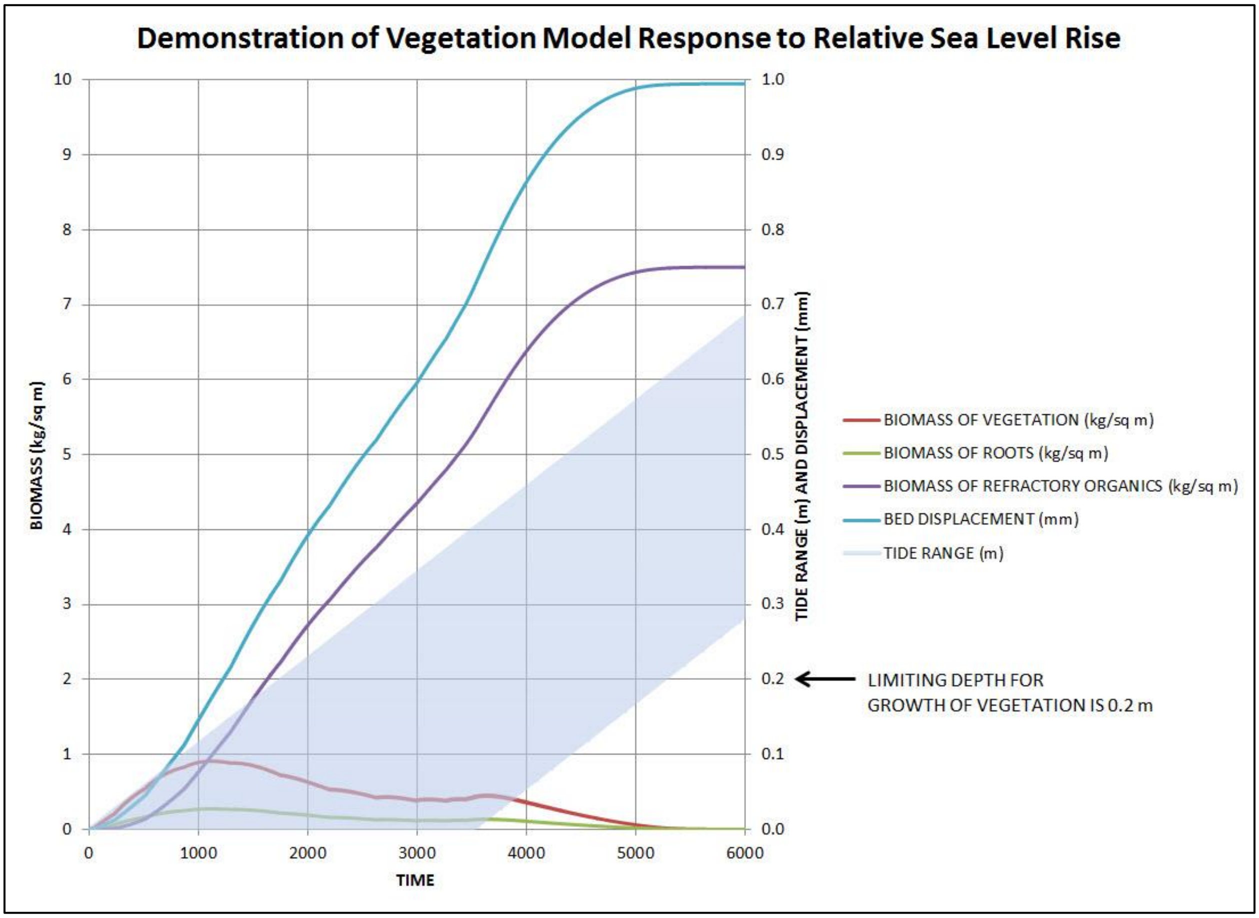


Figure 2: Demonstration of Wetland Vegetation Model

Reference

Fagherazzi, S., et al. (2012), Numerical models of salt marsh evolution: Ecological, geomorphic, and climatic factors, Rev. Geophys., 50, RG1002, doi:10.1029/2011RG000359.

Appendix B: AdH/SEDLIB Boundary Condition and Bed Initialization Tips

Sediment Boundary Condition Development and Bed initialization are always challenging, but crucial, parts of sediment modeling. Ill-considered sediment boundary conditions can result in errant, and potentially unstable, model results. The sediment bed represents the history of the river, so initializing it precisely would require a very long model simulation (on the order of decades) to replicate the spatial characteristics of the strata thicknesses and composition.

Here are some helpful tips to allow the model to approximate the correct boundary and bed conditions, without having to perform decadal simulations.

Cohesionless Sediment.

Boundary conditions can be applied using observed data, but if the observed concentrations are not consistent with the concentration that the model predicts, the model will quickly correct the concentrations by eroding or depositing the necessary sediment. Hence, it is often better to allow the model determine the inflowing sand and gravel concentrations. This can be done, for example, as follows:

- Include at least one meander length of river upstream of the area of modeling interest. This is to be used as a boundary condition adjustment zone.
- Use the NDM card to ensure that bed displacement is turned off in this reach. This allows gradational adjustments to the bed without altering the bed elevations.
  - If NDM option 0 is used, the sediment supply is limited to what is present in the bed.
  - If NDM option 1 is used, the sediment supply is unlimited, but the sediment mass is not conserved (i.e. the reach is essentially a boundary condition reach).
- Apply an EQ TRN card to the upstream boundary for each of the sand or gravel classes. This card provides the model with the equilibrium values at the boundary (i.e. that value for which each sediment class is in equilibrium with respect to the bed: there is no net erosion or deposition).
  - Note that EQ TRN cards are not restricted to the model boundary. A node string can be placed anywhere in the mesh, and the EQ TRN card can be assigned there (this is because EQ TRN is applied as a Dirichlet boundary, where the concentration is specified explicitly, as opposed to Natural (Neumann) boundaries, where the flux is specified). So, for some models, it is advantageous to apply the EQ TRN at some short distance downstream of the inflow boundary, so that the model has some ability to adjust the inflowing velocity distribution to a realistic condition before the sediment boundary is imposed.

Bed initialization is best accomplished by first approximating the bed conditions with initial bed layer conditions, and then allowing the model to run through an initialization period to adjust this estimated bed such that armoring and winnowing in the high energy areas can occur (and fining in the low energy areas).

- Using observed bed gradational data, initialize the sediment bed thicknesses and gradation. Bed thickness can be applied in one of two ways.
    - Thickness by layer (NBL option 0). This is the default method, and is straightforward.
    - Thickness by bottom elevation threshold (NBL Option 1). In this method, an elevation horizon is given for the bottom of each bed layer. See the documentation for more details. This method allows horizontal strata to be defined, rather than constant thicknesses.
- Once the sediment bed has been approximated, the model should be simulated through a representative hydrologic event (such as a flood hydrograph) to generate spatially varying initial bed conditions. This is best done using NDM (no bed displacement) cards with option 1 (i.e. sediment mass is not conserved, but the bed elevation and the solid boundary elevation are help constant).
- Once this spin-up simulation is completed, build a full sediment hotstart file from this run, and then run the model using this hotstart, with the NDM cards that were used for initialization either turned off (disabled) and/or converted to NDM option 1 cards (that are mass conservative).

Cohesive Sediment

Boundary conditions should be applied using observed data. Rating curves can be used, but cohesive sediment tends to be poorly correlated to river discharge, since the first flush of a hydrograph tends to have much higher concentrations than other parts of the hydrograph.

Bed conditions are highly dependent on observed data. For simulations were erosion is not of great concern (e.g. reservoir deposition, or floodplain deposition), it is possible to get good modeling results using nominal (literature) values to populate the erosion characteristics. For this case, it is only important to have data concerning the settling characteristics of the sediments. (i.e. are they flocculated, what is their size breakdown?)

If, however, erosional characteristics are important (such as reservoir scour under very high flow), it is crucial to have observed data from some type of erosion testing apparatus (e.g. SEDFLUME). Properly characterizing fine sediment erosion characteristics will require a significant investment if sufficient data are to be collected to support the modeling. The model is only as good as the input data, and the erosion characteristics of cohesive beds tend to be spatially heterogeneous and to vary over orders of magnitude. So these erosion data are necessary to develop a good model.

Some typical values of these parameters are given below. These are loosely based on values taken from The USBR Erosion and Sedimentation Manual (2006). These are approximate. Local observational data are always preferable to approximated values.

- *Settling Velocity* - .01 mm/sec (free settling of fines) to 10 mm/sec (large flocs)
- *Critical Shear for Deposition* – 0.06 Pa to 0.15 Pa
- *Critical Shear for Erosion* - .05 Pa to 1.0 Pa
- *Erosion Rate Constant* - .001 kg/m^2/s to 0.1 kg/m^2/s
- *Erosion Rate Exponent* – 1 to 3

Appendix C: Morphologic Time-Scaling with Modified Porosity

Theoretical Foundation of Modified Porosity Scaling

In order to investigate long-term (multi-annual to multi-decadal) morphological changes, it is useful to develop a means whereby morphologic change can be "accelerated" within the model. For quasi-steady conditions (i.e. slowly-varying conditions) a simple and straightforward method of estimating this acceleration is to scale the porosity of the sediment. Consider the basic equation of mass conservation for a sediment bed (for simplicity, this is shown for a bed consisting of one grain class only, but the same principles apply for a multi-grain class sediment bed).

$$D - E = \rho s\left(1 - p\right)\frac{\partial \eta}{\partial t} \tag{1}$$

That is, the deposition flux minus the erosion flux is equal to the density of sediment, times one minus the porosity, times the time rate of change of the bed elevation.

If we wish to accelerate the rate at which the same net flux (deposition minus erosion) will change the bed elevation by some acceleration factor β, we can substitute into Equation 1 and solve for the porosity necessary to achieve this acceleration (p_β).

$$D - E = \rho s\left(1 - p\right)\frac{\partial \eta}{\partial t} = \rho s\left(1 - p_\beta\right)\beta\frac{\partial \eta}{\partial t} \tag{2}$$

$$\boxed{p_\beta = 1 - \frac{1}{\beta}\left(1 - p\right)} \tag{3}$$

Where ρ is the density of water and s is the specific gravity of the sediment.

Figure 1 demonstrates how porosity scaling works for a wetland formed under steady inflow conditions.

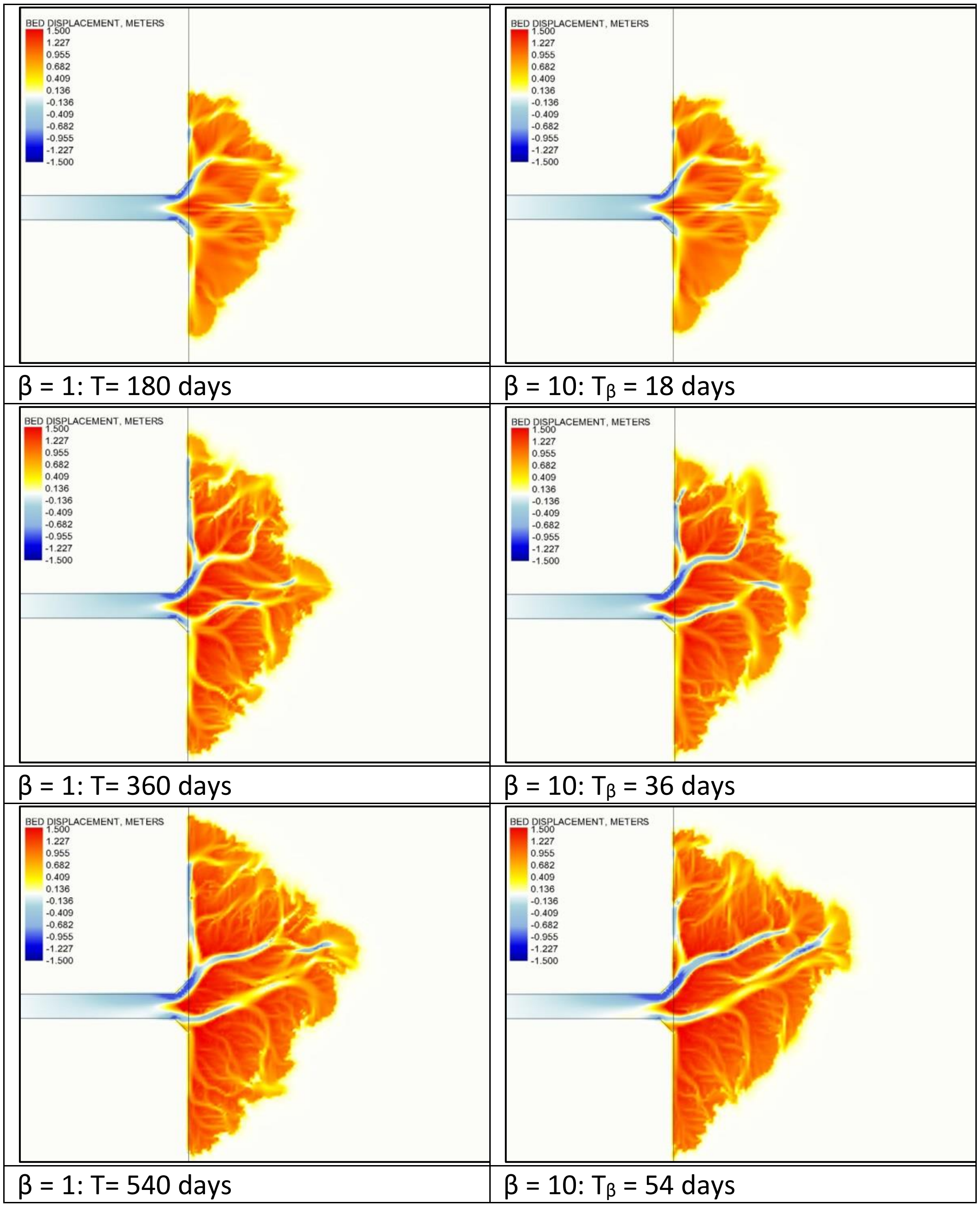


Figure 1: Demonstration of Porosity Scaling for a Wetland Formed by a Steady Inflow of Water and Sediment

Practical Limits of Modified Porosity Scaling

Note that porosity scaling is only strictly valid for steady flow conditions. When unsteady conditions are present, time scaling will scale the relative magnitude of the temporal terms in the mass and momentum equations by the same scale factor (β).

For a typical river hydrograph, using a value of β that is too large will result in significant changes in the velocities, due to rapid rise and fall of the hydrograph in the scaled condition. These changes will alter the erosion and deposition patterns of the river, and hence the porosity scaling method of time acceleration would yield invalid results.

If there are short period variations in the time series data for the inflow boundary and/or the stage boundary, it may be useful to filter these data to smooth these variations. Note, however, that this filtering should only be done if the short period variations are not significant factors in the morphologic evolution of the system.

There is no systematic way to determine what the maximum allowable value of β is for any given project. Therefore, for each project, it is important to perform a numerical test (such as the one demonstrated in Figure 1) to ensure that the selected value of β yields morphologic results that are sufficiently similar to the unscaled results to permit the use of porosity scaling for the project. The results of this test should be included in the project reporting.

The time series associated with the hydrograph data should be scaled by the inverse of β. For example, if β =10 and the total elapsed time of the hydrograph (T) is 10 years, then the total elapsed time of the scaled hydrograph(T_{β}) should be 10/10 = 1 year. This is how model performance is improved: since the model time step is unchanged, the model will run 10 times faster than it would have without the porosity scaling.

Regardless of the results of the sensitivity analysis, it is recommended that the value of β never exceed 10. This is because values larger than 10 result in very large values of scaled porosity, which in turn can result in asymptotic errors associated with the projection of bed change (note that Equation 1 is a function of (1 –p), which asymptotically approaches 0 for large values of p).

Inclusion of High Frequency Periodic Forcings (e.g. tides).

It has been noted that this scaling cannot be applied to high frequency variations, such as tidal conditions, because scaling this high frequency signal would dramatically alter the resulting velocities. However, if it is assumed that the influence of the high frequency signal is largely periodic, the signal can be modeled without scaling if the *number* of cycles within a simulation is scaled. For example, if β=10, T=10 years, and there are 360 cycles in 1 year (e.g. a 24hr tidal signal), the river and tide can be modeled within the same model as follows:

- River: β=10, T_{β} =1 year
- Tide: β=1, T_{β} =1 year, total number of tides modeled = 36.

Again, testing of these methods should be performed for any specific application before they are used to assess scenarios.